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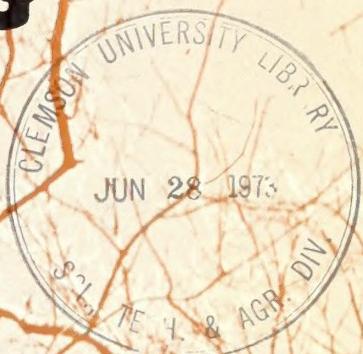
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**a guide to
HARDWOOD
LOG GRADING**

(Revised)

**by Everette D. Rast
David L. Sonderman
Glenn L. Gammon**



**U.S.D.A. FOREST SERVICE GENERAL TECHNICAL REPORT NE-1
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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
WARREN T. DOOLITTLE, DIRECTOR

FOREWORD

THIS GUIDE was developed primarily as a teaching aid and reference for use in training sessions and demonstrations of hardwood log classification and grading. It includes material that amplifies information presented in a different form elsewhere, as well as material developed especially for demonstration. The information in this publication has been developed and assembled since the late 1940's. The basic information was first distributed in mimeograph form in 1947 by R. D. Carpenter and C. R. Lockard at the Southern Forest Experiment Station. It was revised and rewritten in 1951, 1958, and 1960. In 1963 it was assembled in its present format by M. D. Ostrander and published by the Northeastern Forest Experiment Station. Over the years it has proven useful for developing proficiency in evaluating hardwood logs and trees.

This third printing of the guide (the second was in 1965) has been updated and revised in the light of recent research findings. The text and illustrations have been clarified to make this guide easier to understand and the application of the various log classifying and grading systems more efficient and accurate.

The authors gratefully acknowledge the helpful comments and suggestions of Forest Service log-grade specialists R. L. Brisbin, R. D. Carpenter, L. F. Hanks, M. D. Ostrander (retired), and J. A. Putnam (retired).

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a guide to **HARDWOOD LOG GRADING**

Abstract

A GUIDE TO HARDWOOD LOG GRADING (Revised) was developed as a teaching aid and field reference in grading hardwood logs. Outlines basic principles and gives detailed practical applications, with illustrations, in grading hardwood logs. Includes standards for various use classes.

The Authors

EVERETTE D. RAST received his bachelor of science degree in forestry from the University of Missouri in 1960 and his master of science degree in agricultural economics from Ohio State University in 1970. He joined the U.S. Forest Service in 1960 as a forester on the Mendocino National Forest and in 1966 transferred to the Northeastern Forest Experiment Station. He has served since that time as a research forest products technologist on the quality and grade of hardwood timber project at Columbus, Ohio.

DAVID L. SONDERMAN, research forest products technologist, received his bachelor of science degree in forestry from West Virginia University in 1962. He joined the Northeastern Forest Experiment Station in June 1962 and was formerly on the staff of the eastern softwood timber quality project until June 1972. He is presently with the Northeastern Station's project on quality and grade of hardwood timber at Columbus, Ohio.

GLENN L. GAMMON, a research forest products technologist, received his bachelor's degree in forestry from the University of Georgia, and his master's degree in wood technology from the University of New Hampshire. He joined the Central States Forest Experiment Station in 1963. He is presently on the staff of the Northeastern Station's hardwood timber quality project at Columbus, Ohio.

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The Hardwood Timber Resource

OF THE 2 trillion board feet of merchantable timber standing on forest lands of the United States, about one-fifth—400 billion board feet—is hardwood. One hundred fifteen commercial species produce sawed products; 74 of these same species also produce veneer.

These commercial hardwood species grow on half of the nearly 483 million acres of commercial forest land in the country and they produce one-fourth of all the lumber cut. The annual harvest of hardwood trees for lumber and other wood products amounts to about 12.3 billion board feet.

Fabricating this raw material into finished consumer goods is a complex business. Hardwoods vary greatly in their intrinsic qualities, both within and between species. Some, like yellow birch, cherry, persimmon, and walnut, have highly desirable qualities that put them almost in the class of precious woods. Others, like beech, boxelder, and scarlet oak, have qualities that make them much less desirable, so that there is usually less demand for them. The wide distribution and variety of species, together with these great variations in attributes in and between species and the intricacies of utilization, create both technical and economic problems in evaluating a species' utility.

Log Grades in General

OBJECTIVES OF LOG GRADING

A major objective of log classification is to separate from woods-run logs those that are suitable for the manufacture of a given product or class of products (veneer, standard lumber, ties, etc.) and, for each kind or class so separated, to determine the relative qualities of products obtainable from grades of logs with common surface characteristics. Other objectives are to establish basic specifications for log merchantability, to guide manufacturing processes and methods, to increase the efficiency of sampling for various forestry purposes, and to provide the basis for tree grades.

Some people judge usefulness of a log-grading system by simplicity or ease of application. This is not a sound approach. *Whether log grades are suitable for a given objective depends not upon how easy they are to use but upon how well they meet stated performance standards.* In the task force report prepared for the Forest Service Log Grade Committee (10), the objectives and the application of standards are discussed in considerable detail. For example, in the hardwood factory-lumber log grades, the Forest Service standards require that the system must:

1. Separate from woods-run logs those that are logically suited for sawing into standard factory lumber.
2. Segregate such logs into high-, medium-, and low-quality groups (grades) determined by the lumber-grade yield pattern and gross lumber value they will produce when sawed into lumber in an adequate mill by a sawyer skilled in the production of standard graded hardwood lumber.
3. Provide a substantial differential in average lumber value between the several log grades, and minimize the overlapping of values of individual logs in the different grades (as

when a low-grade log cuts out better than a log of equal size in a higher grade).

4. Perform on small numbers of logs (say 25 to 50 logs) as well as on larger numbers.

5. Use terms and methods sufficiently objective so that men with a reasonable amount of training and experience can apply them in a practical way to a wide range of activities (timber appraisal, timber management, log sale or purchase, production control, or research).

POOREST LOG CONCEPT

Any system for grading raw material must provide a floor: a limit below which the material is not acceptable for conversion. Thus, a *poorest log* is specifically described even though it is recognized that its specifications may vary from time to time with changing economic conditions. If material below this arbitrary minimum is utilized, it becomes merely another group of bole segments, usually of minor significance, which can be evaluated separately. When the use does not include everything down to the poorest log, as defined, the minimum can be raised to the next higher standard classification.

A practical definition for a standard minimum hardwood log is: Any piece of a tree stem 8 inches or more in diameter and 8 feet or more in length, with sweep not exceeding one-half the diameter of the small end; with not more than two-thirds the gross volume in scalable defect; and with any number of knots, holes, rotten areas, etc.—provided the diameter of none exceeds one-half the diameter of the log at point of occurrence. A log is separated from a bolt by a length specification: bole segments 8 feet or more in length are called logs; those under 8 feet are generally called bolts. The potentially usable material in a hardwood tree is illustrated in figure 1.

**TOTAL POTENTIALLY USABLE
CUBIC VOLUME**

**CONVERSION TO PRODUCTS
IMPRactical**

Pieces of wood with crooks, elbows, knotty sections, short pieces, etc., that cannot be handled or piled readily; or any section of a tree that is not practically available, or is too rotten to be used for any product.

**CONVERSION TO PRODUCTS
PRACTICAL**

Stem, top, or limbwood reasonably straight and practically available, with smallest piece 4 ft. long and 4 in. diameter top inside bark.

**SUITABLE FOR OTHER TYPES
OF CONVERSION**

Reasonably straight pieces over 4 ft. long and 4 in. top diameter inside bark that do not meet sawing conversion specifications. Includes pulpwood, charcoal wood, metallurgical wood, fuelwood, and piece products.

**SUITABLE FOR SAWING,
VENEERING, OR BLANKING.**

Figure 1.—The possible products obtainable from the total cubic volume in a hardwood tree.

VENEER LOGS
Suitable for manufacture into veneer for low value chucks and cores of plywood panels) as well as high value products: fancy or face veneer. Veneer logs are graded by numerous local specifications by the Northern Hardwood and Pine Manufacturers' Assn., and interim specification approved by the Chief of the Forest Service for northern hardwood veneer logs.

**FACTORY LUMBER
LOGS**

Suitable for manufacture into lumber to be graded under National Hardwood Lbr. Assn. Rules for Standard Lbr. Factory logs are graded by specifications taken from U.S. Forest Prod. Lab. Rpt. 63, *Hardwood Log Grades for Standard Lumber*, 52 p. illus. 1966.

**CONSTRUCTION
LOGS**

Suitable for products requiring strength of piece. Graded by the National Hdwd. Lbr. Assn. rules for construction lumber, or the American Society for Testing Materials standard specifications for structural wood joists and planks, beams and stringers, and posts and timbers.

**SAW OR VENEER
BOLTS**

Pieces 6 in. or more d.b. small end and 3 to 8 ft. long.

LOGS

Pieces 8 in. or more d.b. small end and 8 ft. or longer, with other characteristics specified below.

**LOCAL-USE
LOGS**

Suitable for miscellaneous products not necessarily covered by any standard specifications; or suitable for a variety of piece uses, where strength, durability, and appearance are not important requirements. Generally sold in a local or restricted market for such uses as secondary farm buildings, box boards, mine ties, industrial blockings, and misc. local construction. Usually sold direct to user by producing mill.

HARDWOOD LOG USE CLASSES

The many factors that influence log quality can be isolated and their effect gaged only if use is taken into consideration. Not all hardwood logs that exceed the minimum specifications are equally suitable for all products, even though the quality requirements may be similar. However, four log-use classes are enough to cover current hardwood utilization practices. They are as follows:

1. *Veneer Class.*—This class includes the very high value logs as well as some relatively low value logs. Many logs that qualify for factory-lumber grades 1, 2, and 3 can also be utilized as veneer logs.

Interim specifications for northern hardwood veneer logs (birch, beech, maple, and cherry) were approved by the Chief of the Forest Service in March 1964 for use in timber appraisals in Region 9 and that part of Region 8 that is in the southern Appalachian Mountains.

2. *Factory Class.*—This type of log is adapted to the production of boards that later can be remanufactured so as to remove all defects and obtain the best yields of clear face and sound cuttings.

The grade of lumber cut from such logs is determined by specifications of the National Hardwood Lumber Association grading rules for standard lumber (fig. 2) (9). These grades specify the minimum yield of defect-free material from boards in each grade. High-grade boards are those that will yield high percentages of clear face cuttings in relatively large sizes. Low-grade boards are those that yield small percentages of clear face and sound cuttings.

3. *Construction Class.*—This class includes logs suitable for sawing into ties, timbers, and other items to be used in one piece for structural purposes. Grade specifications are contained in the construction-lumber section of the National Hardwood Lumber Association rules; the tie specifications of the American Railway Association (1); and the standard specifications for structural wood joists and planks, beams and stringers, and posts and timbers of the American Society for Testing Materials.

In general, these specifications are designed to insure the strength of the piece. In the usual run of logs suitable for this use, position and condition of the heart center are especially important. Knots and other defects that would impair the strength of the product are limited to sizes that hold the impairment within acceptable limits.

Although factory-lumber grades allow more defects in the lower grades, construction lumber specifications prohibit weakening imperfections equally in all grades. This results in log requirements different from those for factory-lumber use. For example, a factory log with a rotten, shaky interior, and having large but widely spaced surface defects may produce enough high-grade boards to yield a high average quality. Yet such a log would be practically worthless as a construction log (see figure 8, fourth illustration).

4. *Local-use Class.*—In general, local-use logs are those that are suitable for products not usually covered by standard specifications. High strength, great durability, or fine appearance are not required for the following types of products: crating, pallet parts, mine timbers, industrial blocking, secondary farm buildings, etc. Whereas the other three classes are usually sold over a wide area and through a variety of marketing channels, local-use materials are generally sold directly to the user by the producer. This often makes local-use logs rather profitable.

Within the veneer, construction, and local use classes we may need further separation by grades. The grade specifications are designed to separate logs into value groups based on product requirements. There is no implied price relationship between any grade in one class and any grade in another class. There may be no basic price distinction between classes. The value of the products in the various classes, and of the grades from which they can be made, depend upon the processing equipment and operating methods of the operator. For example, a mill that converts construction-class logs has an entirely different value basis from a mill processing factory-lumber logs. The local-use class usually has the least value, but this does not mean that logs in this class are unprofitable.

Figure 2.—Basic grade specifications for hardwood lumber.^a

Grade	Minimum Specifications				
	Length ^b (feet)	Width (inches)	Yield of rough lumber in clear cuttings ^c (percent)	Size of cuttings	Cuttings ^d (number)
Firsts & seconds	8	6	83 1/3	4" x 5' or 3" x 7'	1 to 4
Selects	6	4	Better face is seconds; reverse side of cutting is sound, or reverse side of piece is 1 Common.		
1 Common	4	3	66 2/3	4" x 2' or 3" x 3'	1 to 5
2 Common	4	3	50	3" x 2'	1 to 7
Sound wormy			Full log yield of 1 Common and better, with worm holes, knots, etc. not over 3/4 inch; stain admitted into cuttings.		
3A Common	4	3	33 1/3	3" x 2'	No limit
3B Common	4	3	25 ^e	1 1/2" & containing not less than 36 sq. in.	No limit

^a The basic grade specifications for hardwood lumber were adapted from the rule book of the National Hardwood Lumber Association (Chicago, Jan. 1971-Jan. 1975) pp. 17-23.

^b Percentage of short lengths is limited by grades: for example in First only 12 percent can be 8 feet to 9 feet; in 2C, 10 percent can be 4 feet to 5 feet.

^c A. *Clear face cutting:* A cutting having one clear face (ordinary season checks admitted) and the reverse side sound as defined in "sound cuttings." The clear face of the cutting shall be on the poor side of the board except when otherwise specified. Admissible defects: ordinary season checks, unlimited sapwood, mineral streaks and spots, burls, and stain provided it will dress out.

B. *Sound cuttings:* A cutting free from rot, pith, shake, and wane. Texture is not considered. It will admit sound knots, bird pecks, stain, streaks or their equivalent, season checks not materially impairing the strength of the cutting, pin, shot, and spot worm holes. Other holes 1/4" or larger are admitted but shall be limited as follows: One 1/4" in average diameter in each cutting of less than 12 units; two 1/4" or one 1/2" to each 12 units and on one side only of a cutting.

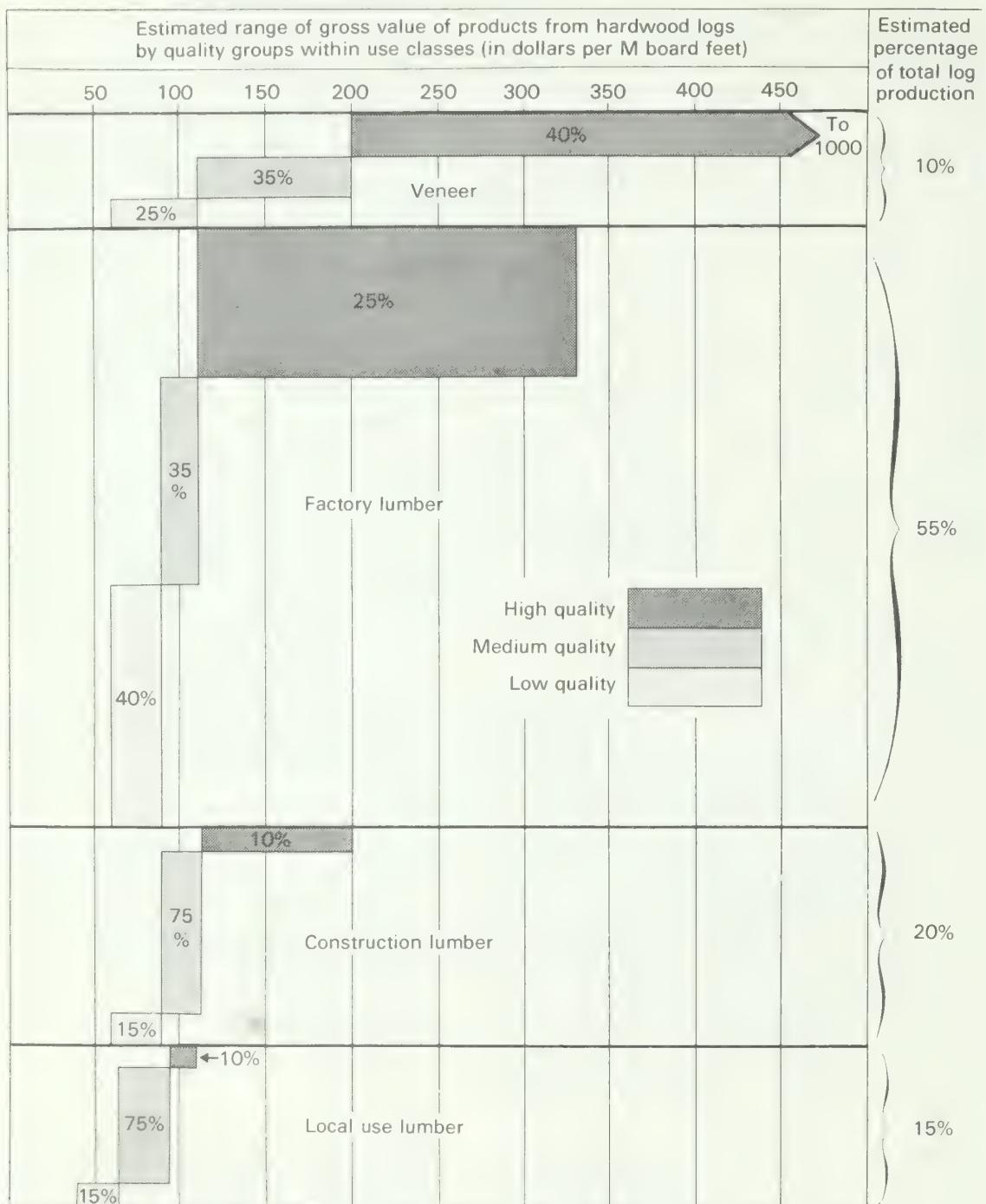
^d Number varies with surface measure of piece; for example, in 1C with surface measure of 5 feet to 7 feet, two cuttings are allowed; in 1C with surface measure of 11 feet to 13 feet, four cuttings are allowed.

^e On basis of sound cuttings; lumber is suitable for low-grade crating and dunnage.

The comparative values, as illustrated in figure 3, provide the log grader with the basic information for choosing the best possible grading system that reflects the business situation for which grading is to be the control. The values for veneer are log values, whereas those of the other three classes are lumber values, because the prices of piece veneer would be unrealistic in relation to lumber prices.

For example, at a standard lumber mill first grading choice is the factory-lumber class. However, at many lumber mills the veneer class logs will be withdrawn first for shipment to a hardwood veneer and plywood plant. After the grader has selected the logs that meet the specifications for factory grades 1, 2, and 3, (F1, F2, F3) he will, in all probability, be left with a residue of lower quality logs. Either he does not grade these, considering

Figure 3.—Range of product values for major use classes of logs.



Note: Height of vertical bar distances represents proportion of log volumes.

RANGE OF PRODUCT VALUE PER M³

Use Class	High-Quality Logs	Medium-Quality Logs	Low-Quality Logs	All Logs
Veneer logs	200-1000	115-200	65-115	320
Factory lumber	110- 330	90-110	60- 90	120
Construction lumber	115- 200	90-115	60- 90	105
Local Use lumber	95- 110	65- 95	40- 65	80

* Values for veneer are log values; all others are lumber values.

them all merely sub-grade logs; or he sorts out the logs that will make the next most valuable class, construction lumber. Any further residue then falls into the local-use class—provided, of course, that they meet the minimum specifications.

This method of grading is a one way street, for logs not suitable for the first classification may be suitable for a lower class.

OTHER PRODUCTS

So far, we have been concerned primarily with veneer, lumber, and timbers, and it may seem that inadequate attention has been given to other products such as cooperage, dimension stock, handle stock and specialties. However, multi-product logging has already recognized the need for sorting out the numerous products, including pulp. These items do assume considerable importance locally, and account for about 25 percent of total hardwood utilization. Specialty product specifications are related closely to those for factory lumber because relatively short, clear pieces of practically defect-free wood are required. Limited studies of specialty products have shown that log quality for specialty products can be gaged closely by the hardwood factory-lumber log grading system or modifications thereof.

GRADE DEFECTS AND SCALABLE DEFECTS

The Society of American Foresters in its *Forestry Terminology* defines the term *defect* very broadly as "any irregularity or imperfection in a tree, log, piece product, or lumber that reduces the volume of sound wood or lowers its durability, strength, or utility values."

Defects fall into two main categories: (1) those that reduce the volume of sound wood or lower its durability; and (2) those that lower its strength, take away from its appearance, or otherwise limit its utility. The first are *scalable defects* (rot, shake, etc.). The second are *grading defects* (knots, stain, etc.).

The term *defective timber* popularly con-

notes rotten or over-mature trees, but such trees may contain much usable material. The amount of scalable defect, together with size limitations, is often the main criterion of merchantability of logs or trees. Actually, logs from which *unusable material* (scalable defect) will be removed in manufacture are not necessarily defective in grading terms, for there may be no grade defects in the remaining usable wood.

On the other hand, perfectly sound trees (without scalable defect) may be worthless because of grade defects that cannot be eliminated in manufacture. The distinction between scalable defects and grade defects is not always clear-cut. Small volumes of scalable defect may be left in the product, affecting strength or utility or lowering product grade by detracting its appearance; they then become grade defects.

Usage gives the term "grade defect" to abnormalities or irregularities on the log surface as well as to imperfections in the wood. These outside features are really indicators of imperfections in the underlying wood and could be termed "grade defect indicators." For example, a branch stub is an indicator of a knot in the product to be sawed from the log. Nevertheless, because timber appraisers deal with logs or tree stems as such, and not as sawn products, this publication designates these surface features as log grade defects or degraders. On the other hand, imperfections in the wood are designated as product grade defects. Further discussion of this can be found in U. S. Department of Agriculture Handbook No. 244, *Grade Defects in Hardwood Timber and Logs* (7).

The importance of use class in grading becomes apparent when log grade defects are considered. In one use class a certain irregularity or imperfection in the wood is a product grade defect, so the defect indicator on the log surface is a log grade defect. In another use class, the same irregularity or imperfection does not degrade the product, so the defect indicator on the log surface is not a log grade defect. An example of this is a $\frac{1}{4}$ -inch sound knot. In factory lumber this is a product grade defect; in construction logs it is not (table 1).

Table 1.—Classification of log surface abnormalities

Abnormalities	Factory Logs	Construction Logs	Local-Use Logs
<i>Log surface</i>			
Bulges:			
Butt	Defect	Defect	No defect
Stem	Defect	Defect	No defect
Bumps:			
High	Defect	(3)	(3)
Medium	Defect	(3)	(3)
Low	(2)	(3)	(3)
Burl	Defect	Defect	(3)
Butt scar	Defect	(3)	No defect
Butt swell	No defect	(3)	(3)
Canker	Defect	Defect	No defect
Conk	Defect	Defect	No defect
Dormant buds	(2)	No defect	No defect
Epicormic branches	(2)	No defect	No defect
Flanges	No defect	No defect	No defect
Flutes	(3)	(3)	No defect
Fork	Defect	Defect	No defect
Gum lesions	(3)	No defect	No defect
Holes:			
Large	Defect	(3)	(3)
Medium:			
Bark scarrer, fresh	No defect	No defect	No defect
Bark scarrer, old	Defect	No defect	No defect
Birds, light	No defect	No defect	No defect
Birds, heavy	Defect	No defect	No defect
Grub	(2)	No defect	No defect
Increment borer	Defect	No defect	No defect
Tap	Defect	No defect	No defect
Small	(3)	No defect	No defect
Log knots:			
Sound	Defect	(3)	(3)
Unsound	Defect	(3)	(3)
Limbs	Defect	(3)	(3)
Overgrowths:			
Knots & bark pockets	Defect	(3)	No defect
Insects	Defect	No defect	No defect
Bird peck	Defect	No defect	No defect
Bark distortions:			
Heavy or medium	Defect	No defect	No defect
Light	No defect	No defect	No defect
Seams	(2)	(3)	No defect
Splits	(3)	(3)	No defect
Surface rise	No defect	No defect	No defect
Wounds:			
New	No defect	No defect	No defect
Old	(3)	(3)	No defect
Log end			
Bird peck	(2)	No defect	No defect
Bark pocket (crotch)	Defect	Defect	No defect
Double pith	No defect	Defect	No defect
Grease spots	(2)	No defect	No defect
Grub channels	(2)	(3)	No defect
Gum spots	(2)	No defect	No defect
Loose heart	(1)	Defect	No defect
Rot	(2)	Defect	No defect
Shake:			
Ring	(2)	Defect	No defect
Wind	(2)	Defect	No defect
Soak	(3)	No defect	No defect
Spider heart	(2)	Defect	No defect
Stain	(2)	No defect	No defect
Worm holes:			
Pin, flag & shot	Defect	No defect	No defect

(1) Defect if not confined to heart center & inner quality zone.

(2) Refer to Special Instructions for Factory Logs (page 16).

(3) Refer to Grade Defects in Hardwood Timber and Logs, Agr. Handbk. No. 244.

Definition and Application of Specifications for Hardwood Log Classes and Grades

HARDWOOD VENEER-LOG CLASS

The term *veneer* includes not only fancy or face veneer but also veneer suitable for the backs and cores of plywood panels and veneer for containers.

It has been commonly assumed that veneer logs must be of exceptionally high quality and that only a small proportion of factory grade sawlogs will qualify as veneer logs. Comparison of the Forest Service factory-lumber log grade specifications with the veneer-log specifications of the Northern Hardwood and Pine Association indicates that this assumption is incorrect. U.S. Forest Products Laboratory Research Paper FPL-13, *Changes in Mill Run Hardwood Sawlog Lumber Grade Yields When Veneer Logs Are Withdrawn* (12), shows that a varying proportion of both grade 1 and grade 2 factory lumber logs will qualify as veneer logs. The material for backs and cores of plywood panels and veneer for containers definitely allows the small sound defects generally permitted in the cuttings of the lower common grades of factory lumber. Logs suitable for these lower classes of veneer are often found among grade 3 factory-lumber logs.

At present there is no standard system for grading veneer logs that is based on research. However, there are numerous local grade specifications, such as those published by the Northern Hardwood and Pine Manufacturers' Association and the American Walnut Manufacturers' Association. Because they are generally based on limited information about the factors influencing veneer-log quality, these systems could be improved. Studies made by the Forest Products Laboratory have provided the veneer grades necessary to develop such specifications for logs. These are contained in

Forest Products Laboratory Research Paper FPL-9, *Recommended Veneer Grades for the Development of Hardwood Veneer Log Grades* and Forest Products Laboratory Note 025, *Using the FPL Hardwood Veneer Grades*.

Late in 1963, the leader of the Hardwood Log Grade Project was authorized by the Washington Office, Division of Timber Management, to develop veneer-log specifications to be used in Forest Service timber sale appraisals. In cooperation with the regions involved, the project leader developed a set of interim specifications for northern hardwood veneer logs (fig. 4), recommended mainly for the northern hardwood species: beech, birch, maple, ash, and cherry. These were approved by the Chief of the Forest Service in March 1964 for use in timber appraisals in Region 9 and that part of Region 8 that is in the southern Appalachian Mountains.

These specifications are based on limited information about the factors that influence veneer-log quality, but they are definite and explicit enough to be applied directly. They should not be considered final, but merely a bridge between the present and the time when additional studies supply the data for developing standard veneer-log grades and accompanying veneer-grade yield tables.

The interim specifications clarify specific grading factors, and are quite similar to the Northern Hardwood and Pine Association specifications. Adventitious bud clusters and small branches (less than $\frac{1}{2}$ inch) are disregarded because they will normally disappear in "rounding up" the log.

The specifications define use classes. They provide a sound basis for separating potentially fancy or face veneer quality material from factory-lumber logs, and they are applicable to both cut logs and standing trees.

Figure 1.—Northern Hardwood Veneer Log Specifications.^a

Grading Factors	Specifications
1. Length	8 feet and over plus 6 inches trim allowance. ^b
2. Diameter (minimum)	12 inches d.i.b.—small end. ^c
3. Sweep	$\frac{1}{4}$ inch per foot of log length
4. Crook and/or catface	1 admitted in logs of all lengths and diameters if it can be contained in a 2-foot long scaling reduction from either end, or from within the log provided that a cutting at least 52 inches long remains on each side of the scaled out portion.
5. Spiral Grain (maximum)	$\frac{1}{2}$ inch per foot of log length
6. Crotch	Crotch admitted in logs of all diameters provided it can be cut off by deducting 1 foot of length in scaling.
7. Seam	None admitted which enter the right cylinder in logs 12, 13, and 14 inches d.i.b. Logs 15 inches d.i.b. and larger admit one seam, entering the right cylinder, provided that it diverges from a straight line between the log ends no more than $\frac{1}{2}$ inch per foot of log length. Such a seam constitutes 1 standard defect.
8. Standard Defect (other than seam) Knots, worm holes, dead or rotten areas, high bumps (with height over length ratio greater than 1 to 6), heavy bark distortions and old bird pecks (4 or more per sq. ft.). ^d Treat any number as 1 standard defect when located not more than 10 inches from an end or so located that they can be included in a 1-foot reduction in log length when the log is scaled.	One standard defect admitted in logs 8 through 10 feet long, 2 in logs 12 feet and, 3 in logs 14 through 16 feet.
9. End Defects A. Black heart and/or mineral stain	Admitted in hard maple logs when not in excess of $\frac{1}{2}$ the scaling diameter.
B. Hole, rot, ring shake, loose or spider heart, and heart checks	Admitted when confined to a central core around the geometric center of the log end and the last 2 feet of log length—subject to scaling reduction. ^d After scaling reduction: Logs 12, 13, and 14 inches d.i.b. can contain central core with long axis no longer than 3 inches; logs 15 inches d.i.b. can contain central core with long axis no longer than 4 inches; and logs 16 inches and over d.i.b. can contain central core with long axis no longer than 6 inches.
C. Knots, partial ring shake, worm holes, bird pecks, stain spots, incipient rot areas, and bark pock-ets	Admitted to all logs outside the central core (9B) when confined to a $\frac{1}{4}$ segment of one end. When occurring on both log ends, must be confined to same $\frac{1}{4}$ segment in logs 12 through 15 inches d.i.b., can be in different $\frac{1}{4}$ segments in logs 16 inches d.i.b. and larger.

^a Recommended mainly for northern hardwood species of beech, birch, maple and cherry.

^b 7-foot lengths are accepted by most mills; 6 foot lengths are accepted by most mills for black walnut.

^c Select Veneer Grade—Logs 14 inches and over d.i.b. must be free of all defect except for the allowable unsound central core (9B) and sweep (3).

^d Logs subject to 2 foot scaling reduction in length due to unsound central core (9B) permit unlimited surface defects over the 2 feet so treated (8).

**FOREST SERVICE STANDARD
GRADES FOR HARDWOOD
FACTORY-LUMBER LOGS**

The factory-lumber log class has been divided into three grades. The specifications for these grades (fig. 5) are closely correlated with the specifications for standard hardwood lumber grades, the grade of the log depending largely on the proportion of log length that is obtainable in clear cuttings (table 2).

The major factors that affect the quality of factory-lumber logs are: (1) position of log in tree (butt or upper); (2) size of log, especially diameter; (3) straightness; (4) amount and distribution of scalable defects; and (5)

Table 2.—Minimum length of clear cuttings by log length and proportion required

Log Length (feet)	5/6	3/4	2/3	1/2
Feet and inches				
8	7' 4"	6' 0"	5' 4"	4' 0"
9	7' 6"	6' 9"	6' 0"	4' 6"
10	8' 4"	7' 6"	6' 8"	5' 0"
11	9' 2"	8' 3"	7' 4"	5' 6"
12	10' 0"	9' 0"	8' 0"	6' 0"
13	10' 10"	9' 9"	8' 8"	6' 6"
14	11' 8"	10' 6"	9' 4"	7' 0"
15	12' 6"	11' 3"	10' 0"	7' 6"
16	13' 4"	12' 0"	10' 8"	8' 0"

Figure 5.—Forest Service standard grades for hardwood factory lumber logs.^a

Grading Factors	Log grades							
	F1			F2			F3	
Position in tree	Butts only	Butts & uppers		Butts & uppers			Butts & uppers	
Scaling diameter, inches	13-15 ^b	16-19	20+	11+ ^c	12+		8+	
Length without trim, feet	10+		10+	8-9	10-11	12+	8+	
Required clear cuttings ^d of each of 3 best faces ^e	Min. length, feet	7	5	3	3	3	3	2
	Max. number	2	2	2	2	2	3	No limit
	Min. proportion of log length required in clear cutting	5/6	5/6	5/6	2/3	3/4	2/3	1/2
Maximum sweep & crook allowance	For logs with less than 1/4 of end in sound defects	15%			30%			50%
	For logs with more than 1/4 of end in sound defects	10%			20%			35%
Maximum scaling deduction	40% ^f			50% ^g			50%	
End defect:	See special instructions (page 18)							

^a From USDA Forest Service Research Paper FPL-63 (13).

^b Ash and basswood butts can be 12 inches if they otherwise meet requirements for small #1's.

^c Ten-inch logs of all species can be #2 if they otherwise meet requirements for small #1's.

^d A clear cutting is a portion of a face, extending the width of the face, that is free of defects.

^e A face is 1/4 of the surface of the log as divided lengthwise.

^f Otherwise #1 logs with 41-60% deductions can be #2.

^g Otherwise #2 logs with 51-60% deductions can be #3.

defects in the usable wood outside the heart center. *Heart center* is used in a restricted sense; it is a cylinder in the center of the log with a radius equal to one-fifth of the scaling diameter.

The Forest Service Standard Grades for Hardwood Factory Lumber Logs call for grading the three best faces. After taking into account the size and soundness of the log, the grader visually squares the log full length into four faces so oriented as to give the largest number of good faces. Each face is evaluated the same way a board would be evaluated, with the exception that rip and sound cuttings are not allowed; all cuttings must be clear and full width of face. The poorest face of the log is eliminated. The grade of the log is then determined by the poorest of the three remaining grading faces (fig. 6). In practice it is possible for a trained grader to pick out the controlling or grading face by a quick inspection only, and make the necessary measurements on this face.

The major problem in grading factory-lumber logs is to locate clear cuttings. This requires the proper evaluation of surface indicators of defects. Branch stubs and knot overgrowths are clearly evident, so they present no problem. But the grader usually needs some training and experience to detect and evaluate accurately other less obvious indicators.

Once the faces have been graded, the log ends must be examined for grade defect indicators that may not show on the log surface. These are provided for by special instructions for evaluating end defects (page 18) and by the general restriction on the percentage of scaling deduction allowed in each grade. Minimum diameter, minimum length, maximum allowable sweep, and position of the log in the tree are also important grading factors. Examples of the three factory-lumber log grades are shown in figures 7, 8, and 9.

Lumber grade yields will vary by species and diameter within log grades. The yield of No. 1 Common and Better lumber for factory

Figure 6.—Selecting the grading face.

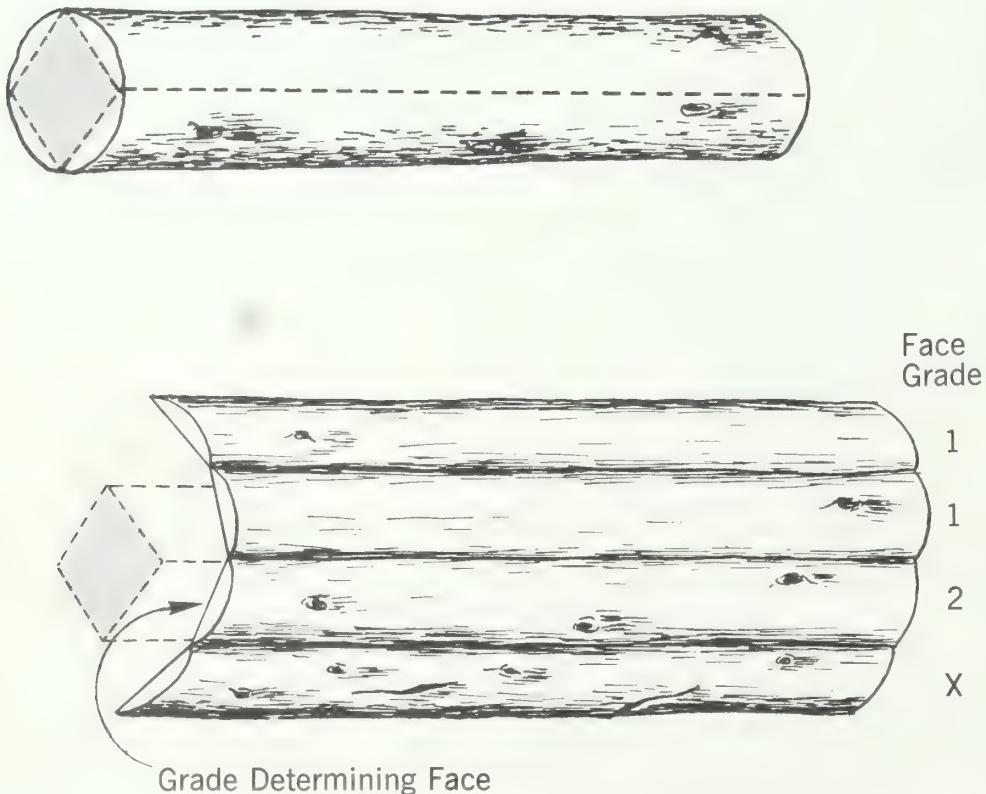
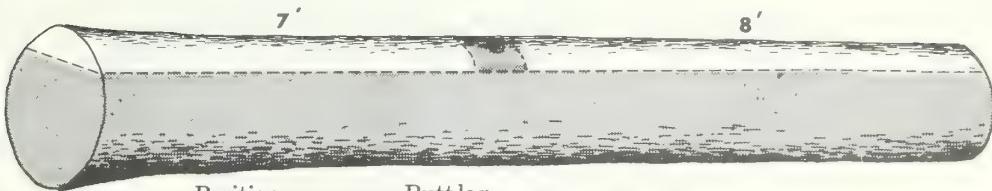
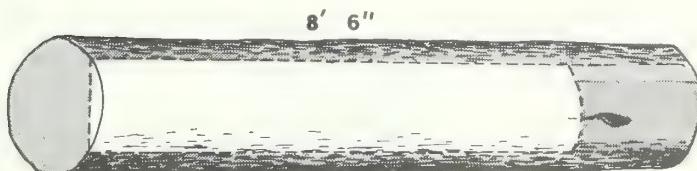


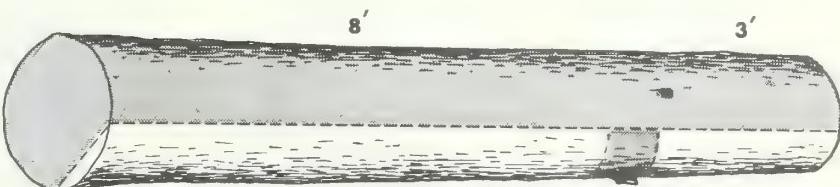
Figure 7.—Examples of hardwood factory grade 1 logs.



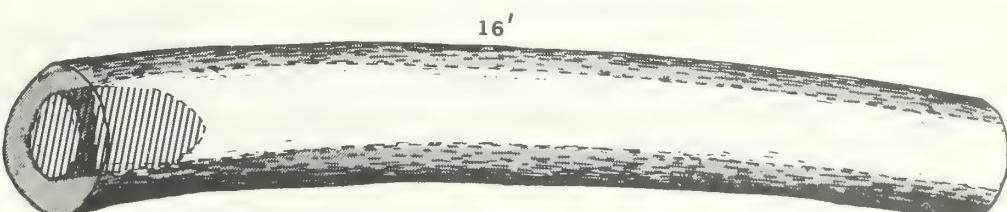
Position Butt log
 Size Length 16', diameter 13" at small end
 Straightness Straight
 Soundness Sound
 Cuttings More than 5/6 of its grading-face length is clear
 in two sections 7 and 8 feet long



Position Upper log
 Size Length 10', diameter 16" at small end
 Straightness Straight
 Soundness Sound
 Cuttings More than 5/6 of its grading-face length is clear
 in one section 8 feet 6 inches long

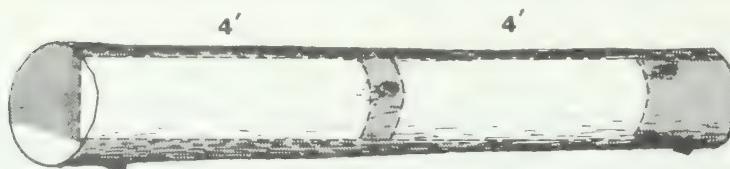


Position Upper log
 Size Length 12', diameter 20" at small end
 Straightness Straight
 Soundness Sound
 Cuttings 5/6 of its grading-face length is clear in two sec-
 tions 8 and 3 feet long

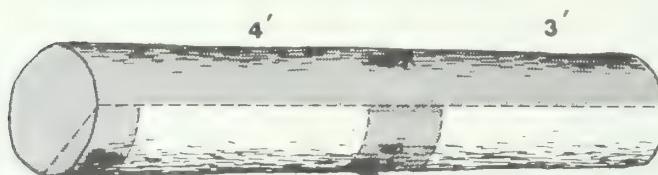


Position Upper log
 Size Length 16', diameter 20" at small end
 Straightness 10 percent deduction for 4" of absolute sweep
 Soundness 5 percent deduction for center rot (sweep and
 rot deductions less than 40 percent maximum
 permitted)
 Cuttings One cutting 16'
 Comments Rot is confined to permissible rot zone and does
 not affect clear grading face

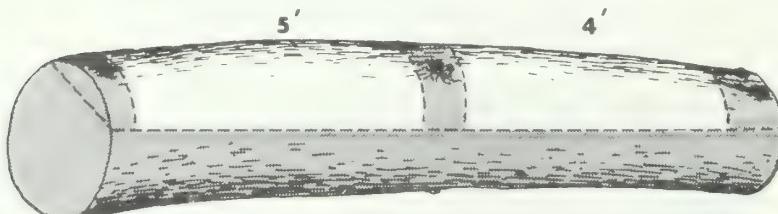
Figure 8.—Examples of hardwood factory grade 2 logs.



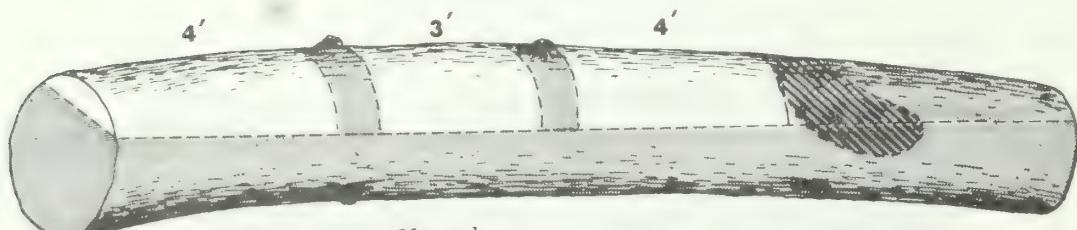
Position Upper log
 Size Length 10', diameter 11" at small end
 Straightness Straight
 Soundness Sound
 Cuttings More than $\frac{1}{2}$ of its grading-face length is clear in two sections each 4 feet long



Position Upper log
 Size Length 9', diameter 12" at small end
 Straightness Straight
 Soundness Sound
 Cuttings More than $\frac{3}{4}$ of its grading-face length is clear in two sections 4 and 3 feet long

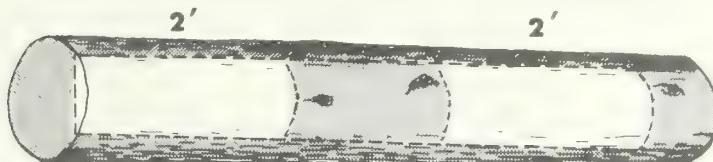


Position Upper log
 Size Length 11', diameter 18" at small end
 Straightness Deduction of 28 percent for 6 $\frac{1}{2}$ inches of absolute sweep (sweep less than 30 percent maximum allowance)
 Soundness Sound
 Cuttings More than $\frac{2}{3}$ of its grading-face length is clear in two sections 5 and 4 feet long

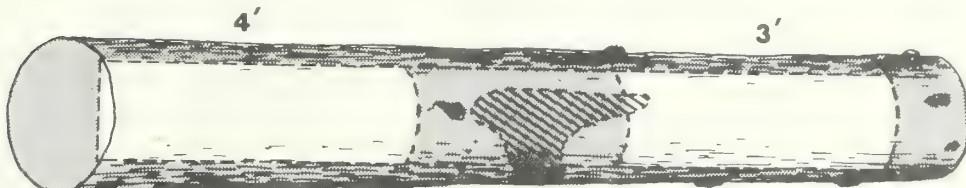


Position Upper log
 Size Length 16', diameter 22" at small end
 Straightness 9 percent deduction for 4 inches of absolute sweep
 Soundness 20 percent deduction for rot (sweep and rot deductions less than 50 percent maximum permitted)
 Cuttings Rot limits cutting on grading face, but clear cuttings of 4, 3, and 4 feet give more than the required $\frac{2}{3}$ of grading-face length

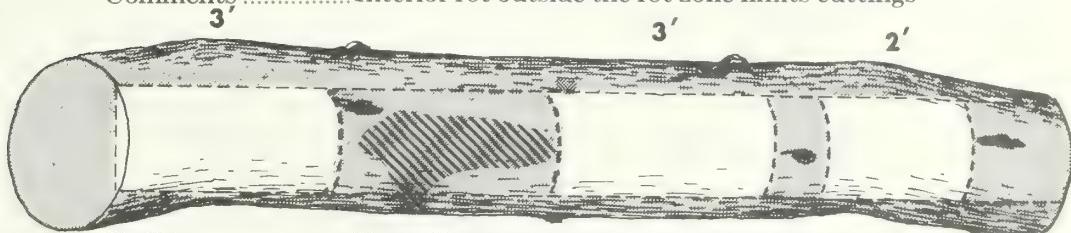
Figure 9.—Examples of hardwood factory grade 3 logs.



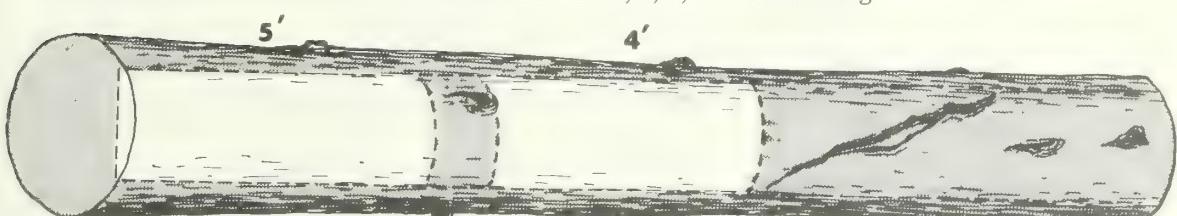
Position Upper log
 Size Length 8', diameter 8" at small end
 Straightness Straight
 Soundness Sound
 Cuttings One-half of its grading-face length is clear in two sections, each 2 feet long



Position Upper log
 Size Length 12', diameter 14" at small end
 Straightness Straight
 Soundness 15 percent rot deduction (less than 50 percent maximum permitted)
 Cuttings More than $\frac{1}{2}$ of its grading-face length is clear in two sections, 4 and 3 feet long
 Comments Interior rot outside the rot zone limits cuttings



Position Upper log
 Size Length 14', diameter 22" at small end
 Straightness 12 percent deduction for 6" x 3' of crook on both ends of log
 Soundness 15 percent rot deduction (crook and rot less than 50 percent maximum deduction)
 Cuttings More than $\frac{1}{2}$ of its grading-face length is clear in three sections, 3, 3, and 2 feet long



Position Upper log
 Size Length 16', diameter 22" at small end
 Straightness Straight
 Soundness Sound
 Cuttings More than $\frac{1}{2}$ of its grading-face length is clear in two sections, 5 and 4 feet long

grade 1 logs will generally range from 65 percent upward; for factory grade 2 logs, from 40 to 64 percent; and for factory grade 3 logs, from 13 to 39 percent. Detailed grade-yield information is available in U. S. Forest Service Research Paper FPL-63 (13).

SPECIAL INSTRUCTIONS FOR FACTORY LOGS¹

Surface Features

Evaluation of defects.—A surface abnormality, if determined to extend into the log for a depth more than 15 percent of the diameter at the point of occurrence, is a log grade defect. Otherwise, it should be disregarded. All defect indicators judged to indicate log grade defects are counted as equal, with the following exceptions in factory logs only:

1. Epicormic branches:
 - a. Large (limbs more than $\frac{3}{8}$ inch diameter at origin or bark surface): full defect on logs of all sizes, grades, and species.
 - b. Small (limbs $\frac{3}{8}$ inch diameter or less):
 - (1) Hard hardwoods² (except black cherry, where they are not counted as defects): All grades: On logs less than 14 inches: full defect. On logs 14 inches and more: one-half defect; i.e., skip every other one.
 - (2) Soft hardwoods³: Grades 1 and 2: full defect on logs less than 14 inches; one-half defect on logs more than 14 inches. Grade 3: no defect.
 2. Grub holes and grub-caused overgrowths:
 - a. Progressive on face.
 - (1) On logs 8-15 inches: each is a full defect.
 - (2) On logs 16-19 inches: disregard every sixth one.
 - (3) On logs 20-23 inches: disregard every fifth one.
 - (4) On logs 24-27 inches: disregard every fourth one.
 - (5) On logs 28 inches or more: disregard every third one.
- b. Non-progressive—aligned across face.
 - (1) When two or more of these defects are found in a band not more than 6 inches wide across the width of the face they may be considered as one.
 3. Bumps: High and medium bumps must be considered on all logs, although in some species⁴ low bumps can sometimes be disregarded. Measurement of clear cuttings (fig. 10) is affected as follows:
 - a. High bump (length less than three times height: example—6 inches long and 4 inches high): Stop clear cutting at change in contour. Do not enter bump with clear cuttings.
 - b. Medium bump (length three to six times height: example—12 inches long and 2 to 4 inches high): Let clear cutting enter bump one-eighth of the length on each end.
 - c. Low bump (length 6 to 12 times height: example—12 inches long and 1 to 2 inches high): Let clear cutting enter bump one-fourth of the length on each end.
 - d. Surface rise (length more than 12 times height): disregard.
 4. Straight seams, frost cracks, splits (fig. 11), extending into inner quality zone.
 - a. Straight seams extending all or part of the length of the log that can be considered as a line dividing two grading faces can be disregarded.
 - b. Straight seams not confinable to lines dividing grading faces.
 - (1) When full length of log: a full defect.
 - (2) When extending from one end of log towards middle: Include one-third of the seam length on interior end in the clear cutting.
 - (3) When completely in log: extend cuttings one-fourth of seam length from each end.

¹ Based on USDA Agricultural Handbook #4 (8).

² Includes such species as sugar maple, beech, yellow birch, sycamore, hackberry, all oaks and ashes, and hickories.

³ Includes such species as soft maples, basswood, yellow-poplar, gum, magnolia, willow, cottonwood, and elm.

⁴ Includes such species as soft maple, tupelo, soft elm, birch, ashes, magnolias, and white oaks (white, cow, and swamp chestnut).

Figure 10.—Evaluation of bumps in hardwood factory lumber logs.

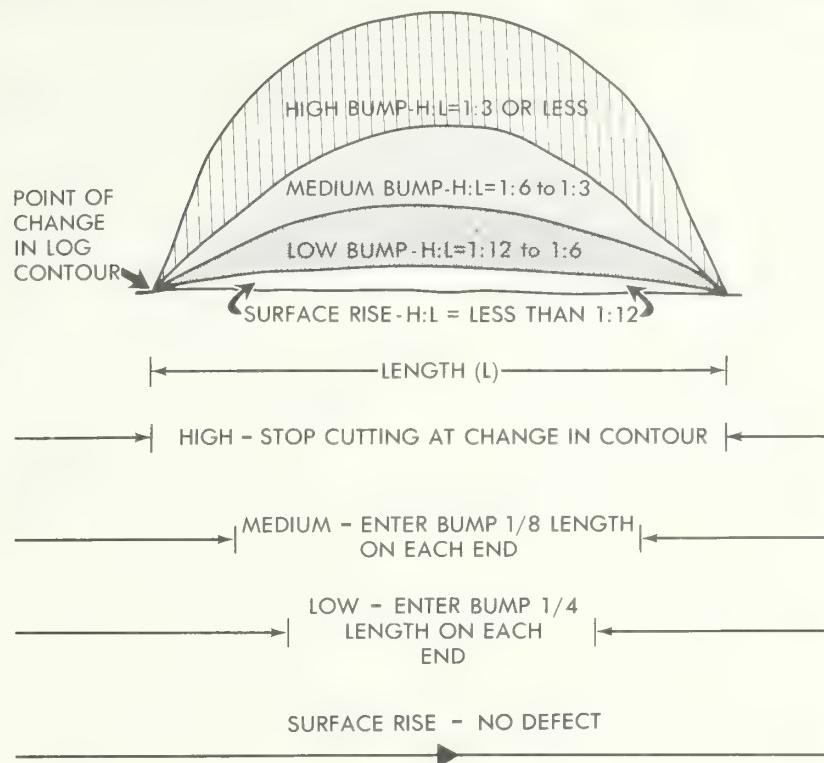
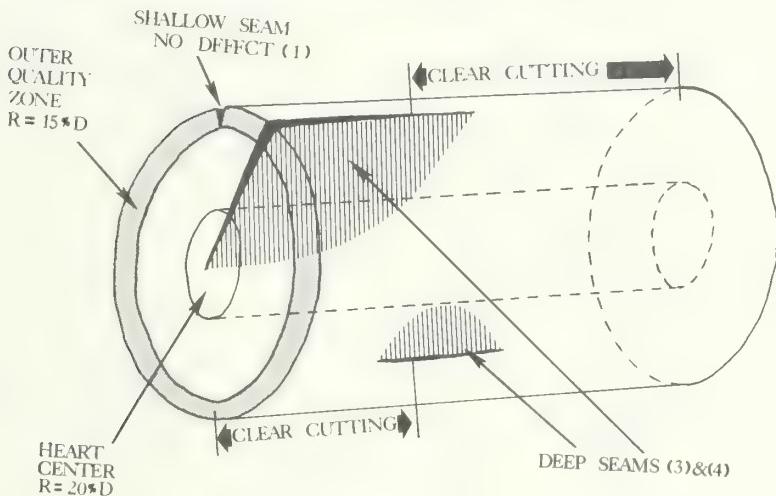


Figure 11.—Evaluation of seams, frost cracks, splits, etc., in hardwood factory lumber logs.



1. A seam, frost crack, split, etc. is not a defect unless it is deeper than 15% of log diameter.
2. No clear cuttings can be taken on a log face that includes a full-length straight seam or a spiral seam. However, one straight seam can be placed on the edge of one face and ignored. This fixes the location of all other defects.
3. A deep seam entering a face but not running full length may be overlaid with a clear cutting for one-third of its length, starting at the inner end.
4. When a deep seam is entirely within a log, clear cuttings can be laid over it from each end for a distance equal to one-fourth its full length.

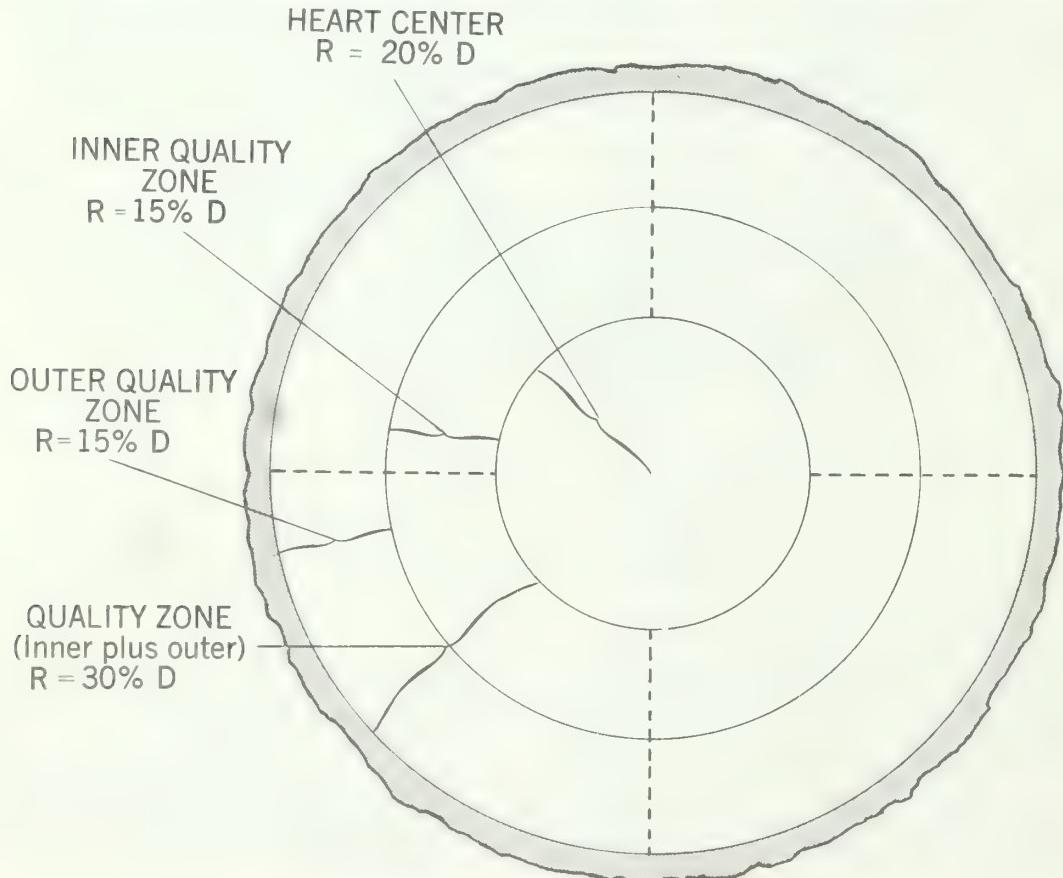
5. Spiral seams, frost cracks, and splits, extending into inner quality zone: stop clear cutting where defect enters face being graded.
6. Bird peck. Individual pecks are not counted; length of pecked area is measured. A pecked area is one containing four or more pecks within 1 square foot.
 - a. Lightly pecked area (fewer than four pecks per square foot): disregard.
 - b. In grade 1 and 2 logs with four or more pecks per square foot:
 - (1) If pecks are open, disregard.
 - (2) If pecks are partially or completely occluded, the pecked area is a defect. (Note: age of peck does not matter; test is whether callus tissue is formed in the peck-holes.)
 - c. In grade 3 logs: disregard all pecked areas.

End Features

1. Definitions

- a. Heart center. Heart center is considered to be a core in the center of the log with a radius equal to one-fifth of diameter (fig. 12).
- b. Quality zone. The portion of the log outside the heart center (fig. 12).
 - (1) Inner quality zone—inside half of quality zone.
 - (2) Outer quality zone—outside half of quality zone.
- c. Affected area. This is defined as the area in which there are blemishes within 3 inches of each other. The total affected area, and not the area of the individual blemishes, is what determines the degrading effect.

Figure 12.—Location of end features in hardwood factory lumber logs.



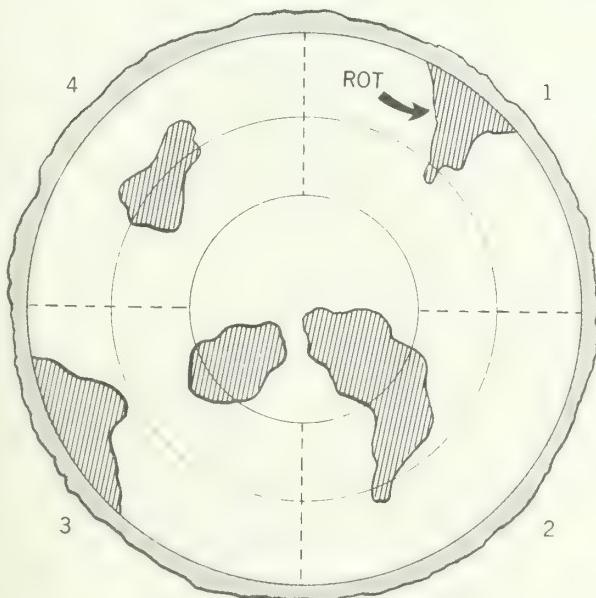
2. Evaluation

- a. All abnormalities, regardless of type, can be disregarded in grading when they are confined to the heart center. However, they may cause scale deductions.
- b. When an abnormality is not confined to the heart center, divide the log end into quarters conforming to the grading faces and evaluate as follows:
 - (1) Rot, heart check and ring shake (fig. 13). If these enter the quality zone in any quarter and are:
 - (a) Confined entirely within the inner or outer quality zone, make scale deductions as usual, but disregard as a log defect.
 - (b) In both inner and outer quality zones, make scale deductions as usual but consider as a defect in the quarter and face involved, as follows:
 - (i) If it extends full length of log, no clear cutting can be taken.

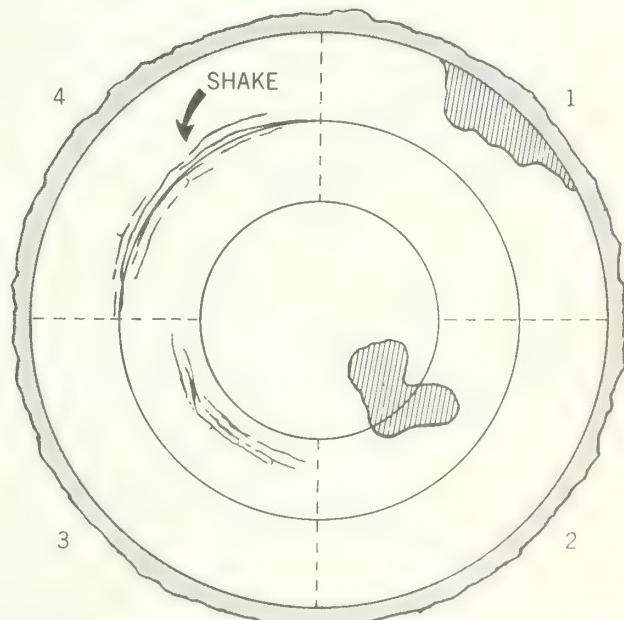
(ii) If it extends only partially through the log, allow cuttings to be measured back toward the log end one-third the length of the affected area from the point where it is estimated that the rot or shake tapers out.

- (2) Spider heart. Defect if not confined to heart center.
- (3) Spot worm holes, shot worm holes, pin worm holes, bird peck, bark pockets, grub holes, gum spots, grease spots. When enough of these are found to constitute an affected area in the quality zone and the radial measurement of this affected area is:
 - (a) In grade 1 and 2 logs:
 - (i) Less than half the radial width of quality zone: disregard.
 - (ii) Greater than half the radius of the quality zone in

Figure 13.—Evaluation of rot and shake in hardwood factory lumber logs.



Rot is defect in all 4 quadrants



Rot no defect in quadrant 1 or 2
Shake no defect in quadrant 3
Shake is a defect in quadrant 4

- three or more quarters on one end, or two or more quarters on both ends: de-grade one grade.
- (b) In grade 3 logs: disregard.
- (4) Stain. This is considered on the scaling end only; disregard if on the large end only. The affected area in this case is the total area involved, *including* the heart center. When stain occurs in several solid areas that are not joined, the extent is the sum of the individual areas.
- Treat as follows:
- (a) In grade 1 and 2 logs:
- (i) If diameter on scaling end is less than half the scaling log diameter, disregard.
 - (ii) If diameter on scaling end is more, drop one grade.
- (b) For grade 3 logs: disregard.

CONSTRUCTION-LOG CLASS (Ties and Heavy Timbers)

This class has not been divided into grades (fig. 14). The major factors that affect the quality of this class of logs are size and condi-

Figure 14.—Forest Service standard specifications for hardwood construction logs.^a

Position in tree		Butt & upper
Min. diameter, small end		8 inches +
Min. length, without trim		8 feet
Clear cuttings		No requirements.
Sweep allowance, absolute		$\frac{1}{4}$ diameter small end for each 8 feet of length.
Sound surface defects	Single knots	Any number, if no one knot has an average diameter above the callus in excess of $\frac{1}{3}$ of log diameter at point of occurrence.
	Whorled knots	Any number if sum of knot diameters above the callus does not exceed $\frac{1}{3}$ of log diameter at point of occurrence.
	Holes	Any number provided none has a diameter over $\frac{1}{3}$ of log diameter at point of occurrence, and none extends over 3 inches into included timber. ^b
Unsound surface defects		Same requirements as for sound defects if they extend into included timber. ^b No limit if they do not.
End defects	Sound	No requirements.
	Unsound	None allowed; log must be sound internally, but will admit 1 shake not to exceed $\frac{1}{4}$ the scaling diameter and a longitudinal split not extending over 5 inches into the contained timber.

^a These specifications are minimum for the class. If, from a group of logs, factory logs are selected first, thus leaving only non-factory logs from which to select construction logs, then the quality range of the construction logs so selected is limited, and the class may be considered a grade. If selection for construction logs is given first priority, then it may be necessary to subdivide the class into grades.

^b Included timber is always square, and dimension is judged from small end.

tion of log defects, straightness, and soundness of heart (table 1). Many logs that fall into this class do not meet the requirements for the factory-lumber class, but are well suited for ties and heavy structural timbers. Sound, straight, small-knotted factory-lumber logs will also meet these specifications. Examples of typical structural-class logs are presented in figure 15.

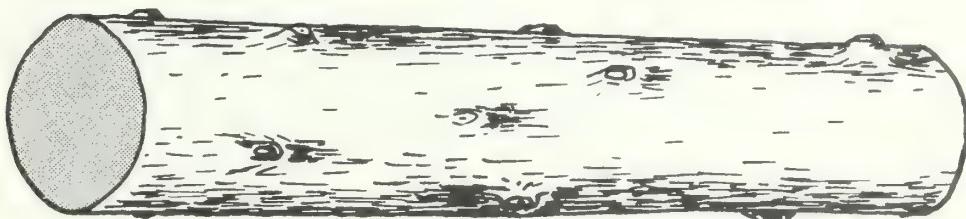
For grading purposes it is considered that the log contains a square timber, the dimensions of which are governed by the small end. Holes are allowed if their depth does not exceed 5 inches from the log surface. Table 3 shows allowable knot size (one-quarter width of face) for the largest squared timber obtainable by log diameters; log knot size (one-third log diameter at point of occurrence) for corresponding log;

maximum sweep allowed per 8 feet of length; and the largest timbers obtainable from a given log, including squared and other commonly stocked dimension timbers.

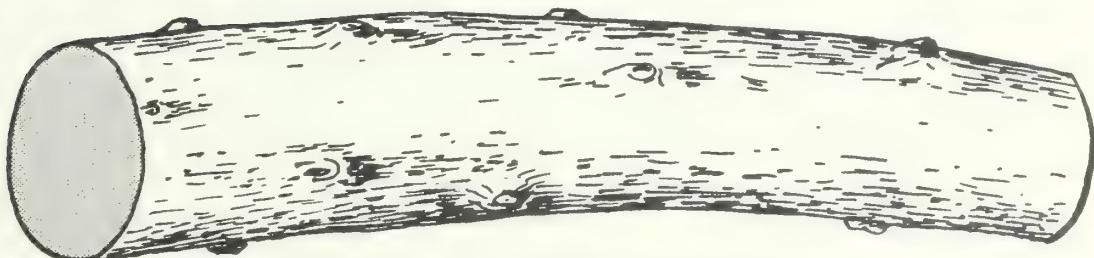
Larger knots could be allowed where dimension timbers other than squares are to be made, but knot diameter cannot exceed one-quarter of the width of the face of the tie or timber on which it occurs. Where it is definite that logs are to be used for ties, knots up to one-half the diameter of the log at point of occurrence are allowable when they are within 12 inches of either end of the log. This exception cannot be applied to standing timber.

Table 3 will also be helpful in estimating the products obtainable from construction logs, and in relating log character to products.

Figure 15.—Examples of hardwood construction lumber logs.



A 10-foot log 18 inches in diameter at the small end. The cuttings on at least two of the four faces are not equal to the minimum required for factory grade 3. Although it has numerous knots, none has a knot collar exceeding $\frac{1}{3}$ of the log diameter at the point where it occurs. The log contains no rot, shake, or splits, and it is straight.



A 12-foot log, 22 inches in diameter at the small end. The cuttings on at least two of the four faces are not equal to the minimum required for a factory grade 3. The numerous knots are small and, although the log is sweepy, the actual sweep does not exceed $\frac{1}{4}$ of the diameter of the small end of the log. There is no rot, shake, or split.

Table 3.—Relationship of log diameter to maximum timber sizes
and allowable knot size, in inches

Log d.i.b. small end (inches)	Average diameter of largest knot allowed on log surface		Maximum sweep or crook per 8 feet (absolute)	Largest timber obtainable (rough, green)			
				Squared		Common dimension	
	Largest squared timber	Log		To nearest $\frac{1}{4}$ inch	To nearest inch		
8	1-7/16	2-2/3	2	5-3/4	6x6 ^a	—	
9	1-5/8	3	2-1/4	*6-1/2	6x6	4x8	
10	1-3/4	3-1/3	2-1/2	7	7x7	6x8 ^c	
11	1-15/16	3-2/3	2-3/4	7-3/4	8x8	4x10	
12	2-1/8	4	3	*8-1/2	8x8	6x10	
13	2-5/16	4-1/3	3-1/4	9-1/4	9x9	8x10	
14	2-1/2	4-2/3	3-1/2	10	10x10	8x12	
15	2-5/8	5	3-3/4	10-3/4	11x11	9x12	
16	2-13/16	5-1/3	4	11-1/4	11x11	6x15	
17	3	5-2/3	4-1/4	12	12x12	7x16	
18	3-3/16	6	4-1/2	12-3/4	13x13	8x16	
19	3-3/8	6-1/3	4-3/4	*13-1/2	13x13	10x14	
20	3-9/16	6-2/3	5	14-1/4	14x14	12x16	
22	3-7/8	7-1/3	5-1/2	*15-1/2	15x15	12x18	
24	4-1/4	8	6	17	17x17	14x20	
26	4-5/8	8-2/3	6-1/2	*18-1/2	18x18	14x22	
28	4-15/16	9-1/3	7	19-3/4	20x20	14x24	
30	5-1/4	10	7-1/2	21-1/4	21x21	14x26	
32	5-11/16	10-2/3	8	22-3/4	23x23	16x28	
						18x26	

^a Class 1 cross-tie.

^b Class 2 cross-tie.

^c Class 3 cross-tie.

^d Class 4 cross-tie.

^e Class 5 cross-tie.

^f Class 6 cross-tie.

* 1/2-inch variation allowed for mismanufacture; i.e., 15-1/2 = 15 x 15 or 16 x 16.

Figure 16.—Suggested specifications for hardwood local-use logs.

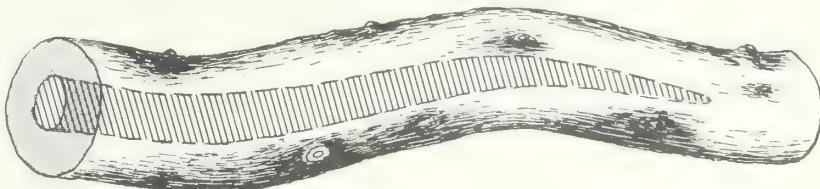
Position in tree	Butt and upper
Min. diameter, small end	8 inches +
Min. length, without trim	8 feet +
Sweep allowance, absolute	$\frac{1}{2}$ diameter of small end
Max. scale deduction allowed	$\frac{2}{3}$
Clear cuttings	No requirements
Sound or unsound surface defect limitations	Only requirement is that diameter of knots, holes, rot, etc. shall not exceed $\frac{1}{2}$ diameter of log at point of occurrence.
Sound end defects	No requirements

HARDWOOD LOCAL-USE LOG CLASS

The standard minimum log as suggested by the Forest Service system is defined in the specifications for miscellaneous or local-use class

logs (fig. 16). Examples are presented in figure 17. Although this standard minimum log may vary with species, locality, and economic conditions, its definition is essential to provide a floor.

Figure 17.—Examples of local-use class logs.



A 14-foot log 16 inches in diameter at the small end. It does not have minimum cuttings required for a factory log. It is too crooked and unsound to meet construction specifications. Sweep and rot deductions are less than 67 percent.



A 12-foot log 18 inches in diameter at the small end. It does not have the cuttings required for a factory log. It has no large knots and no sweep, but it has an unsound heart for which scale deductions will be less than 67 percent.



A 16-foot log 18 inches in diameter at the small end. It does not have the cuttings required for a factory log. Although it is sound, several knots are too large for the construction class.



A 16-foot log 20 inches in diameter at the small end. It does not have the cuttings required for a factory grade 3 log because of the deep spiral seams. It will not qualify as a construction log because of unsound heart.

GENERAL GRADING PROCEDURES

Scaling

Scaling a log is the first step in grading. It not only gives an estimate of the content (table 4), but also gives some of the data needed to apply grade specifications. Scaling should be done carefully, according to standard practices that conform to those used in developing the grading rules. For hardwood sawlogs these are:

Diameter measurement: Average small end, inside bark.

Length measurement: Longest included full foot.

Scaling deductions:

1. *Interior deductions*.—the revised scaling practice developed by Grosenbaugh (4) at the Southern Forest Experiment Station works as follows (rule 5, fig. 18 and Appendix II):

- (1) Enclose defect in circle or ellipse (say, 7 inches x 9 inches on a 20-inch log).
- (2) Measure short and long axis of circle or ellipse in inches and add 1 inch to each measurement (8 inches x 10 inches).
- (3) Determine, for each augmented axis, what percentage it is of log diameter in inches minus 1, and round off to nearest 10 percent ($8/19 = 40$ percent, $10/19 = 50$ percent).
- (4) Determine length of defect as percentage of log length (say, $\frac{1}{4}$ or 25 percent).
- (5) Multiply long axis percentage, short axis percentage, and length percentage together; the result is the percentage deduction ($40 \times 50 \times 25 = 5$ percent).

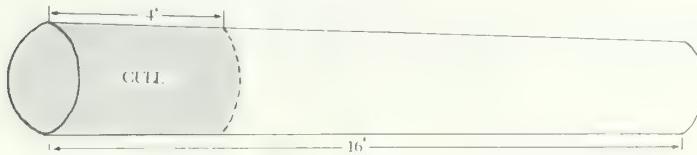
2. *Other deductions*.—Grosenbaugh's rules (rules 1-4, fig. 18) cover these. In determining sweep the number subtracted from actual

Table 4.—International 1/4-inch log rule^a

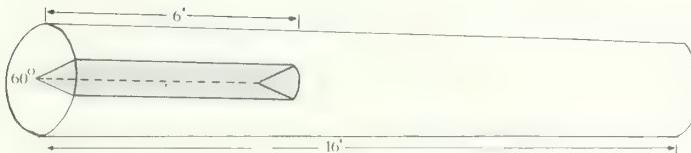
Diameter (inches)	Volume (board feet) according to length, in feet—												
	8	9	10	11	12	13	14	15	16	17	18	19	20
8	15	20	20	25	25	30	35	35	40	40	45	50	50
9	20	25	30	30	35	40	45	45	50	55	60	65	70
10	30	35	35	40	45	50	55	60	65	70	75	80	85
11	35	40	45	50	55	65	70	75	80	85	95	100	105
12	45	50	55	65	70	75	85	90	95	105	110	120	125
13	55	60	70	75	85	90	100	105	115	125	135	140	150
14	65	70	80	90	100	105	115	125	135	145	155	165	175
15	75	85	95	105	115	125	135	145	160	170	180	195	205
16	85	95	110	120	130	145	155	170	180	195	205	220	235
17	95	110	125	135	150	165	180	190	205	220	235	250	265
18	110	125	140	155	170	185	200	215	230	250	265	280	300
19	125	140	155	175	190	205	225	245	260	280	300	315	335
20	135	155	175	195	210	230	250	270	290	310	330	350	370
21	155	175	195	215	235	255	280	300	320	345	365	390	410
22	170	190	215	235	260	285	305	330	355	380	405	430	455
23	185	210	235	260	285	310	335	360	390	415	445	470	495
24	205	230	255	285	310	340	370	395	425	455	485	515	545
25	220	250	280	310	340	370	400	430	460	495	525	560	590
26	240	275	305	335	370	400	435	470	500	535	570	605	640
27	260	295	330	365	400	435	470	505	540	580	615	655	690
28	280	320	355	395	430	470	510	545	585	625	665	705	745
29	305	345	385	425	465	505	545	590	630	670	715	755	800
30	325	370	410	455	495	540	585	630	675	720	765	810	860
31	350	395	440	485	530	580	625	675	720	770	820	870	915
32	375	420	470	520	570	620	670	720	770	825	875	925	980
33	400	450	500	555	605	660	715	765	820	875	930	985	1,045
34	425	480	535	590	645	700	760	815	875	930	990	1,050	1,110
35	450	510	565	625	685	745	805	865	925	990	1,050	1,115	1,175

* Values as published by H. H. Chapman, extended by formula: $V = (0.22D^2 - 0.71D) \times .905$ for 4-foot section. Taper allowance: $\frac{1}{2}$ inch per 4 feet lineal.

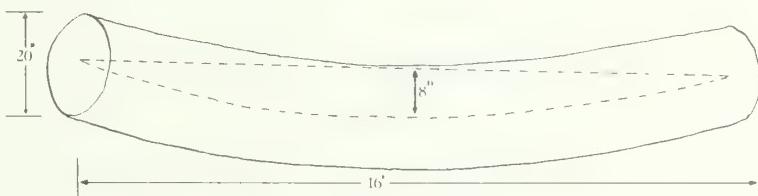
Figure 18.—Methods of determining scaling deduction.
(Examples based on a 16-foot log with 20-inch scaling diameter)



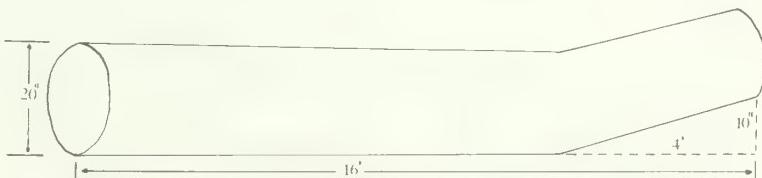
Defect section (rule 1):
 Percent deduction = $\frac{4}{16} = 25\%$



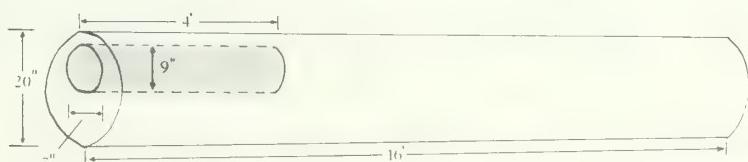
Defect section (rule 2):
 Percent deduction = $\left(\frac{6}{16}\right)\left(\frac{60}{360}\right) = 6\frac{1}{4}\%$



Sweep (rule 3):
 Percent deduction = $\frac{8 - 2}{20} = 30\%$



Crook (rule 4):
 Percent deduction = $\left(\frac{10}{20}\right)\left(\frac{4}{16}\right) = 12\frac{1}{2}\%$



Interior defect (rule 5):
 Percent deduction = $\frac{(8)(10)}{(20 - 1)^2} \cdot \frac{4}{16} = 5\frac{5}{9}\%$

In practice each ellipse axis can be divided by $(20 - 1)$ and rounded to nearest tenth if desired.

Thus $\frac{8}{19}, .4, \frac{10}{19}, .5$, and $(.4)(.5)\left(\frac{4}{16}\right) = 5\%$

sweep depends on log length as follows:⁵ 8 feet thru 10 feet — 1, 11 feet thru 13 feet — 1½, and 14 feet thru 16 feet — 2.

Relation of Scaling Deductions to Log-Grading Defects

In general, making a scaling deduction from the scale of a log up to the limits indicated in

the grading rules does not upgrade the log, even though in some cases it may appear that the existence of a rotten heart center, for which scaling deduction is made, would raise the average grade of usable lumber produced. Parts of the portion for which deduction is made may or may not affect clear cutting areas. If they do, they are individual log grade defects.

⁵ See Table 5 for sweep deduction percentages.

**Table 5.—Sweep deduction from gross scale by length
and diameter (in percent; based on rule 3)**

Absolute sweep in inches		Scaling diameter, average small end inside bark, in inches											
8-9-10 foot logs	14-15-16 foot logs	8	10	12	14	16	18	20	22	24	26	28	30
—	3	12	10	8	7	6	6	5	5	4	4	4	3
3	4	25	20	17	14	12	11	10	9	8	8	7	7
4	5	38	30	25	21	19	17	15	14	12	12	11	10
5	6	50	40	33	29	25	22	20	18	17	15	14	13
6	7	62	50	42	36	31	28	25	23	21	19	18	17
7	8	—	60	50	43	38	33	30	27	25	23	21	20
8	9	—	—	58	50	44	39	35	32	29	27	25	23
9	10	—	—	67	57	50	44	40	36	33	31	29	27
10	11	—	—	—	64	56	50	45	41	38	35	32	30
11	12	—	—	—	—	62	56	50	45	42	38	36	33
12	13	—	—	—	—	—	61	55	50	46	42	39	37
13	14	—	—	—	—	—	—	60	54	50	46	43	40
14	15	—	—	—	—	—	—	65	59	54	50	46	43
15	16	—	—	—	—	—	—	—	64	58	54	50	47
16	17	—	—	—	—	—	—	—	—	62	58	54	50
17	18	—	—	—	—	—	—	—	—	—	62	57	53
18	19	—	—	—	—	—	—	—	—	—	65	61	57
19	20	—	—	—	—	—	—	—	—	—	—	64	60
20	21	—	—	—	—	—	—	—	—	—	—	—	63
21	22	—	—	—	—	—	—	—	—	—	—	—	67
11-12-13 foot logs		3	19	15	12	11	9	8	8	7	6	6	5
4	31	25	21	18	16	14	12	11	10	10	9	8	
5	44	35	29	25	22	19	18	16	15	13	12	12	
6	56	45	38	32	28	25	22	20	19	17	16	15	
7	—	55	46	39	34	31	28	25	23	21	20	18	
8	—	65	54	46	41	36	32	30	27	25	23	22	
9	—	—	62	54	47	42	38	34	31	29	27	25	
10	—	—	—	61	53	47	42	39	35	33	30	28	
11	—	—	—	—	59	53	48	43	40	37	34	32	
12	—	—	—	—	66	58	52	48	44	40	38	35	
13	—	—	—	—	—	64	58	52	48	44	41	38	
14	—	—	—	—	—	—	62	57	52	48	45	42	
15	—	—	—	—	—	—	—	61	56	52	48	45	
16	—	—	—	—	—	—	—	66	60	56	52	48	
17	—	—	—	—	—	—	—	—	65	60	55	52	
18	—	—	—	—	—	—	—	—	—	63	59	55	
19	—	—	—	—	—	—	—	—	—	67	62	58	
20	—	—	—	—	—	—	—	—	—	—	66	62	
21	—	—	—	—	—	—	—	—	—	—	—	65	

Note: For odd lengths and half inches of sweep, deductions can be interpolated from the figures given.

The Application of Log Grades in Timber Cruising

In cruising, the estimator may divide the tree bole into logs of various lengths as he thinks the logger will divide it when it is cut. Then he can grade each log by length, diameter, surface, straightness, and estimated scale deduction, with allowance for effect of hidden end defects, based on local studies.

However, when timber is cruised on a grade basis using conventional volume tables, the bole is divided into 16-foot lengths (or nearest half log) until the top is reached. This bole division may not and generally does not coincide with the way the bole will be bucked in practice. Forest Service studies have shown that bucking to variable lengths to make the best grade logs possible will produce significantly higher lumber yields than are estimated by this standard-log cruising method.

Consideration must also be given to interior rot, shake, or insect damage and their effect on log grade. Although there are few published guides to help timber cruisers, estimating internal scaling deduction is not an unknown art. To begin with, deductions must be estimated to determine whether or not a log is merchantable, for merchantability specifications contain, among other things, a maximum scale deduction.

An unsound interior will effectively exclude a log from the construction class, and perhaps from the veneer class. Within the factory class, scale deduction limits are broad, although the combined effect of sweep and rot narrows the

limits somewhat in crooked logs. Cruisers not accustomed to grading logs in trees sometimes consider it impractical because scale deductions must be made. They overlook the fact that for adequate volume estimates, similar deductions must be made.

Since dividing the bole into 16-foot lengths may underestimate log quality, and dividing as it will presumably be cut is uncertain, the following compromise procedure is suggested:

1. Divide the bole into 16-foot sections, the top section being classed as either a full 16-foot log or an 8-foot half log, as required by the volume table.

2. Grade each full log on a 16-foot length basis. However, if by grading a 12- or 14-foot portion of any 16-foot section, the grade can be improved, then apply this higher grade to the entire 16-foot section. This procedure does not change the number of 16-foot logs in the tree and the d.i.b. of the 16-foot section forms the basis for log grading.

3. Top logs 8 to 15 feet long are graded on the basis of their actual length; if they are longer than 12 feet, apply the same compensatory procedure as in #2 above. Selections 5 to 7 feet long should be graded in the following manner:

- a. Estimate the point 8 feet below actual merchantable height.
- b. Grade the 8-foot section above this point.
- c. Assign this grade to the top half log.

Appendix I

HOW TO USE LOG-GRADE INFORMATION TO ESTABLISH LOG VALUES

Factory-Lumber Logs

Log grades accompanied by lumber grade yields provide the information needed for value determination. U.S. Forest Service Research Paper FPL-63 presents lumber grade yield information by log grade and diameter for several hardwood species. Log overruns and lumber thickness distributions are also covered in the report. One method of obtaining log value is outlined below.

- I. To determine value per Mbft.**
 - a. For each log grade-diameter class apply the percent yields to the lumber tally as shown.
 - b. Apportion the resulting lumber grade volumes into the various thickness classes using either the tabular thickness distribution or one better suited to the situation.
 - c. Apply current lumber prices, published or local, to these lumber grade thickness volumes, and obtain total lumber value.
 - d. Divide this value by total lumber tally; the result is value per Mbft for the log grade-diameter class in question.
- II. To determine log volume.**
 - a. Obtain net scale of a log.
 - b. Estimate lumber volume by applying appropriate overrun to net log scale.
- III. To determine log value.**
 - a. Multiply the estimated lumber volume by the value per Mbft and divide the product by 1,000.

This method of value determination predicts the value of lumber that can be sawed from a log with good sawing practice in a well maintained mill. Differences between actual and predicted values will be quite high for single logs, but will decrease as the number of logs increases. We suggest that 20 logs is the minimum number for which consistent results should be expected.

The following sources of lumber price information should be consulted:

NATIONAL HARDWOOD MAGAZINE, 2029 Peabody Ave., Memphis, Tenn. Prices of southern Appalachian and northern hardwoods, f.o.b. Chicago, are published each month.

HARDWOOD MARKET REPORT, P. O. Box 4042, 28 N. Cleveland, Memphis, Tenn. Prices are published weekly for southern hardwoods, f.o.b. mills in Texas and Louisiana; for Appalachian hardwoods, f.o.b. mills in the Johnson City, Tenn., area; and for northern hardwoods, f.o.b. mills in the Wausau, Wis., area.

COMMERCIAL BULLETIN, Curtis Guild & Co., 88 Broad St., Boston, Mass. New England hardwood and softwood prices are published weekly.

For construction and local-use logs, no graded product information is available. Values must be developed from individual mill experience. The National Hardwood Lumber Association's Rules for the Measurement and Inspection of Hardwood and Cypress Lumber should be consulted for information about other products.

Appendix II

TABLES FOR MAKING INTERIOR SCALE DEDUCTIONS

These two working tables of factors for determining scale deduction are based on Grosenbaugh's Rule 5.

Table 6.—Factors given in this table express the relation of scaling diameter minus 1 (in inches, average d.i.b. of small end) and length of scaling defect section (as estimated to the nearest 10 percent of log length). *Use actual diameter, do not take off an inch.*

Table 7.—This table shows factors that evaluate the cross section of the defect area. *Actual long and short dimensions in inches are used; do not add a collar allowance in measuring.*

To find scale deduction:

1. In Table 6, find factor for log scaling diameter (inches) and length of scaling defect section (percent of log length), i.e., for an 18-inch log with a scaling defect section 30 percent of its length the factor is 0.6.
2. In Table 7, find factor for short and long dimension of defect cross section (i.e., 5 inches x 7 inches = factor 8).

3. Multiply the two factors to get scale deduction in percent of log scale: $8 \times 0.6 = 4.8$ percent. Round to nearest percent = 5 percent.

If this procedure seems cumbersome, consider the sequence. Log length, scaling diameter, and scaling-defect section length can be determined in one operation; cross-section dimensions in another. As the first two (length and diameter) are recorded, the table 6 factor for defect length can be observed and kept in mind. Then, after the cross section is measured, the appropriate factor can be located in table 7 and the two factors can be multiplied mentally.

For logs over 25 inches in scaling diameter, use Grosenbaugh's Rule 5, page 25.

Where cull area goes completely through the log, use the average of dimensions measured on both ends.

Where defect cross-section can be contained in a rectangle instead of an oval, multiply chart values by 5/4.

Table 6.—Scaling diameter : defect length factors

Scaling diameter inches	Percent of log length in cull section									
	10	20	30	40	50	60	70	80	90	100
8	1.2	2.4	3.5	4.7	5.9	7.1	8.2	9.4	10.6	11.8
9	.9	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.1	9.0
10	.7	1.4	2.1	2.8	3.6	4.3	5.0	5.7	6.4	7.1
11	.6	1.1	1.7	2.3	2.9	3.4	4.0	4.6	5.2	5.8
12	.5	1.0	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8
13	.4	.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
14	.3	.7	1.0	1.4	1.7	2.0	2.4	2.7	3.1	3.4
15	.3	.6	.9	1.2	1.5	1.8	2.1	2.4	2.6	2.9
16	.3	.5	.8	1.0	1.3	1.5	1.8	2.0	2.3	2.6
17	.3	.4	.7	.9	1.1	1.4	1.6	1.8	2.0	2.3
18	.2	.4	.6	.8	1.0	1.2	1.4	1.5	1.8	2.0
19	.2	.4	.5	.7	.9	1.1	1.2	1.4	1.6	1.8
20	.2	.3	.5	.6	.8	1.0	1.1	1.3	1.4	1.6
21	.2	.3	.4	.6	.7	.9	1.0	1.2	1.3	1.4
22	.1	.3	.4	.5	.7	.8	.9	1.0	1.2	1.3
23	.1	.2	.4	.5	.6	.7	.8	1.0	1.1	1.2
24	.1	.2	.3	.4	.5	.6	.8	.9	1.0	1.1
25	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Note: Do not take off an inch in measuring diameter.

Table 7.—Interior defect cross-section factors

Short axis, inches	Long axis, inches													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	2	2	3	3	4	4	5	5	6	6	7	7	8	8
3	—	3	3	4	5	5	6	7	8	8	9	10	10	11
4	—	—	4	5	6	7	8	9	10	10	11	12	13	14
5	—	—	—	6	7	8	9	10	11	12	14	15	16	17
6	—	—	—	—	8	10	11	12	13	15	16	17	18	19
7	—	—	—	—	—	11	12	14	15	17	18	19	21	22
8	—	—	—	—	—	—	14	16	17	19	20	22	23	25
9	—	—	—	—	—	—	—	17	19	21	23	24	26	28
10	—	—	—	—	—	—	—	—	21	23	25	27	29	31
11	—	—	—	—	—	—	—	—	—	25	27	29	31	33
12	—	—	—	—	—	—	—	—	—	—	29	32	34	36
13	—	—	—	—	—	—	—	—	—	—	—	34	36	39
14	—	—	—	—	—	—	—	—	—	—	—	—	39	42
15	—	—	—	—	—	—	—	—	—	—	—	—	—	44
16	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Note: Do not add a collar allowance in measuring axes.

Appendix III

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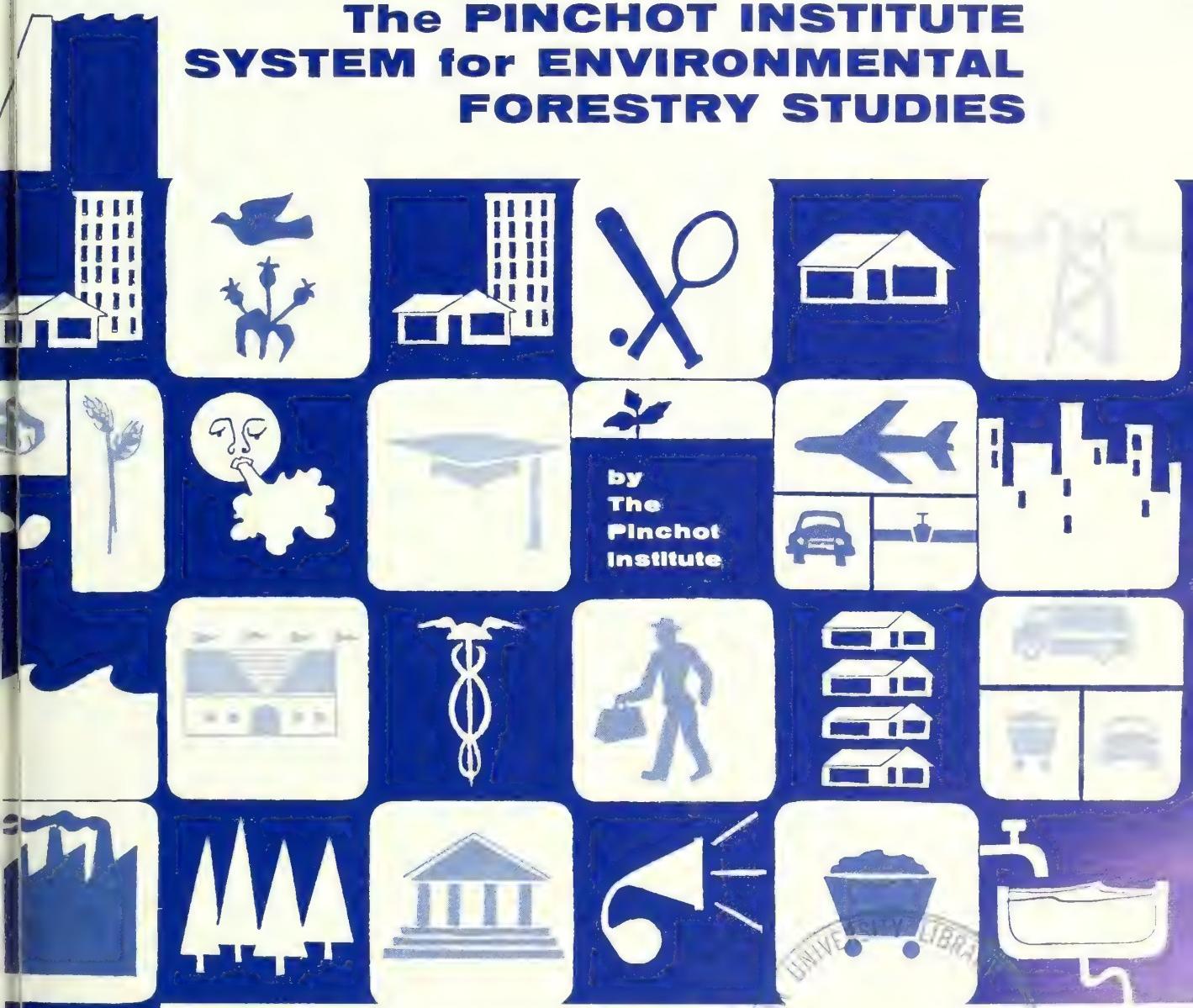




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The PINCHOT INSTITUTE SYSTEM for ENVIRONMENTAL FORESTRY STUDIES



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FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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The Pinchot Institute

ABSTRACT

THIS PAPER describes a prototype system for research planning and administration to meet man's needs for forest vegetation in and around metropolitan areas. The system's components involve social needs or services, technological developments, environmental effects, and the locales where the services, developments, and environmental effects occur. The system is organized from three different perspectives—a social-need viewpoint, a supply-response viewpoint, and an environmental-effect viewpoint. A series of diagrams are presented that show, for each of the three viewpoints, how to formulate and evaluate problems suggested by combinations of various components in the system. Problems that are relevant to the system are those that can be solved by one or more of the following kinds of ecological manipulation procedures of natural forest stands throughout Megalopolis: change or maintain species composition, alter or preserve the density, improve or maintain productivity of an area, and rearrange or hold constant spacial patterns. Examples are provided on how the system can be applied, and various suggestions are made on how to improve it.

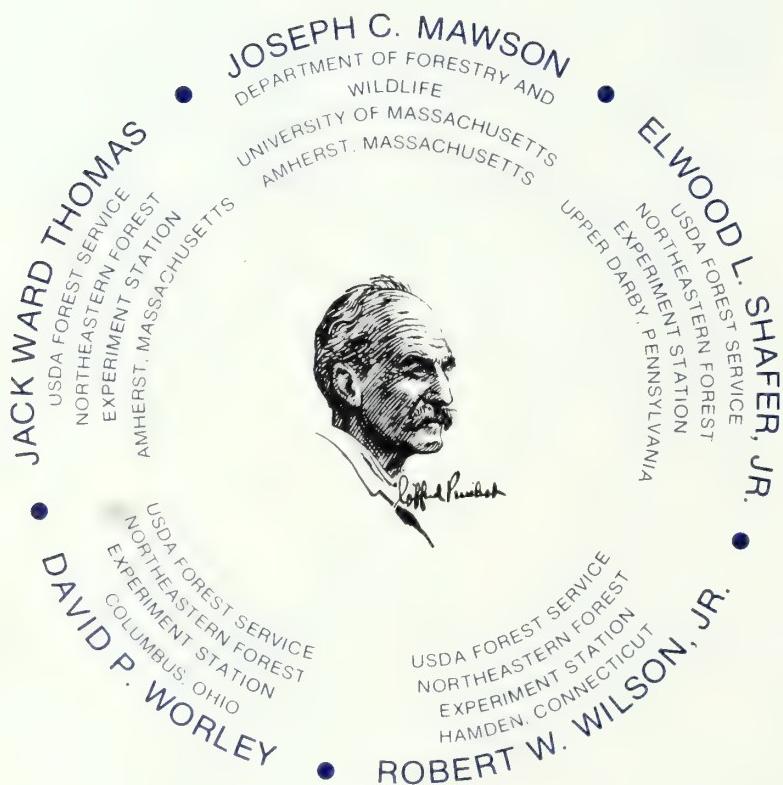
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FOREWORD

THE RESEARCH-PROGRAM development and evaluation system described in this report was developed by an interdisciplinary team of the Pinchot Institute for Environmental Forestry Studies. The members feel that environmental research problems are best attacked by a team effort and that such an effort will be increasingly necessary in research efforts dealing with the interaction of man and his environment. This report is a fruition of that team effort. We believe that our prototype system for research planning and administration can be used, following appropriate modifications, by other disciplines and other government and private institutions in the conduct and administration of almost any type of research dealing with man-resource environmental problems.





A CRISIS

LIKE the Four Horsemen of the Apocalypse—harbingers of war, pestilence, famine, and death—four great threats today confront the ecology of the densely populated Megalopolis of the Northeast: water pollution, air pollution, soil erosion, and destruction of flora-fauna relationships.

In responding to this environmental crisis throughout Megalopolis, the most significant challenges to science are:

1. To establish a systematic research strategy for solving the relevant problems.
2. To set associated research priorities to organize scarce research resources.
3. To proceed, as quickly as possible, with the required research.

To do this, an overall systematic approach is needed that is related to social needs, that considers social controls as devices to achieve these needs, and that stabilizes or improves natural ecosystems required to enhance the social wellbeing of man.

Such a system has been developed by the Pinchot Institute.

THE PINCHOT INSTITUTE

The Pinchot Institute for Environmental Forestry Studies, an interdisciplinary research division of the U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, was created in 1970 to help improve—through environmental forestry research—human environments in the densely populated areas of the Northeast.

Environmental forestry involves those aspects of resource management dealing with man's needs for, and association with, the tangible and intangible values of forest vegetation in and around metropolitan areas. Such forested vegetation involves a wide range of forested conditions—ranging from city park environments to green belts and woodlands in the rural areas that intersperse the huge, sprawling, urban complexes throughout Megalopolis.

Where this forest vegetation exists, it modifies and improves living conditions, furnishes sites for recreation, protects and maintains water supplies, provides sanctuary for wildlife, screens industrial and highway developments, abates noise, reduces temperature, filters dust,

fumes, and other atmospheric impurities, and enhances the setting for aesthetic enjoyment.

The concept of *environmental forestry*, like that of *economics*, cuts across the full fabric of our national life on a broad range of resource-allocation decisions involving such diversified social services and needs as transportation, energy production, housing, employment, health and welfare, education, recreation, and technological development.

The Pinchot Institute involves a coordinated effort of university and Forest Service scientists working together to enhance the social wellbeing of man through the proper management of forest-resource values and effects in and around densely populated areas. The charter of the Institute's Consortium for Environmental Forestry Research describes the organizational procedures for accomplishing a coordinated forest Service-university research effort (appendix I). The Institute's objective is to provide information for megalopolitan decision-makers to help them maintain a proper ecological balance between urban man and his surrounding forest environments.

A STRATEGY

Establishing and administering a comprehensive environmental-research program such as that of the Pinchot Institute might be compared to playing three-dimensional chess. The easiest move is to develop individual research studies within a general problem area. This approach, which is common in environmental research, is like knowing no more about the game than one move that an individual chessman can make.

Deciding on how several research studies should be grouped to provide a satisfactory solution to any one overall general problem area of megalopolitan man parallels the chess player's need to understand how a series of moves on the board complement one another and how one move may affect other moves.

Understanding how groups of studies in each of several research-problem areas fit into a comprehensive research program is similar to the chess player's need to develop a strategy

that allows him to play the game in several dimensions at the same time.

And finally, insuring that the emphasis of a research program is relevant to the total social needs and technological developments of society parallels a chess player's need to know not only how his own, but also how the past, present, and future moves of other players in the game affect the patterns of play.

Our thesis is that, in environmental forestry research, too much attention has been devoted to planning and carrying out the details of individual research studies or groups of studies before adequate effort has been expended in understanding how such studies fit into an overall research program, and how these same studies are oriented to social needs and technological developments.

As environmental scientists, we have been playing in a kind of three-dimensional chess game, but we usually have concentrated our

efforts on only one dimension of the playing surface. In a sense, we have identified the capabilities of a few chess pieces and have developed a few moves on a chessboard that resembles the covers of this publication. However, the odds of winning the total game with such a strategy are extremely small. We believe that the odds of winning—meeting the real needs of decision-makers—can be increased by changing our strategy to one that calls for recognizing the interconnectedness of the problems, the ramifications of the solutions, and the need to prescribe comprehensive research approaches.

Our purpose here is to describe a strategy, or system, for either defining research problem areas for investigation, or for evaluating the effects of social services and technologies on natural forest-resource ecosystems in light of

the overall objectives of the Pinchot Institute.

This is a first-generation system, like a first-generation computer system containing vacuum tubes that could not handle overloads. It has in it a series of information vacuums that we have purposely passed through in tracing the entire flow of the system. At the same time, we recognize that these information vacuums require considerable research and improvement to define important details and interrelationships within the system.

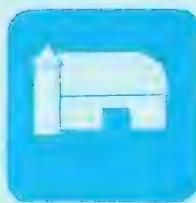
In much the same way that research on transistors and microminiaturization was required to advance computer technology to second- and third-generation systems, additional research is needed on the Pinchot Institute research system to make it more compatible with the present and future needs of metropolitan planners and managers.



SERVICES



LOCALES



DEVELOPMENTS



EFFECTS



THE SYSTEM

The proposed system for Pinchot Institute research deals with the man-dominated section of a forest environment ecosystem. The system is based on the following assumptions:

All changes or status quo conditions in an environmental forestry system can and will be evaluated in terms of services (or needs) required by man. These services are provided in a particular locale through the establishment of technological developments that eliminate or produce certain environmental effects (table 1).

Thus the primary components of the system are *service, locale, development, and environmental effect.* (See appendix II for definitions.)

The key elements listed for each component in the system (table 1) are neither mutually exclusive nor exhaustive of all possibilities, but they serve both to show the scope of the system and to focus on the important elements in each component.

At the outset, it is well to recognize that the system is people-centered and subject to criticism from a purely ecological viewpoint. Any research framework such as this, which deals with environmental problems in the megalopolitan Northeast, could not be otherwise. This intensely human-influenced environment will be a product of man—for either good or ill.

Table 1.—Components of the system for Pinchot Institute research

SERVICES required by man	LOCALES where the services are provided	Technological DEVELOPMENTS used to provide the services	Environmental EFFECTS
<i>Physical infrastructure:</i>			
1. Water supply & waste disposal	1. Urban	1. Heavy industry	1. Air quality
2. Energy provision	2. Suburban	2. Light industry	2. Water
3. Transportation	3. Exurban	3. Power	3. Soil
4. Housing	4. Rural	4. Residences	4. Temperature and humidity
5. Flood control		5. Transportation	5. Noise
6. Recreational structures		6. Cultural and institutional structures	6. Flora & fauna
<i>Institutional infrastructure:</i>			
7. Education		7. Forestry	
8. Employment		8. Agriculture	
9. Health & welfare		9. Mining	
10. Recreational activity			

RESEARCH PACKAGING AND PRIORITY ASSIGNMENTS

The key elements (table 1) were arranged into all possible four-way combinations to contain one key element per component. For example, going from left to right in table 1, the first combination would be:

Service	Locale	Development	Effect
Water supply	Urban	Heavy industry	Air quality

In terms of the numbers that identify these items, this would be designated as a 1-1-1-1 package.

In examining any four-item possibility, we intuitively retained only those packages in which one or more research problems suggested by a package could be solved by one or more of the following four kinds of ecological manipulation procedures:

1. Change or maintain species *composition* of vegetation. Example: The health and welfare (service 9) of youth in urban (locale 2) residences or ghettos (development 4) can be improved in summer by exposing them to maintained *compositions* of water and flora and fauna (environmental effects 2 and 6) in forests near cities.
2. Alter or preserve the *density* of vegetation. Example: The construction of a highway (development 5) in urban areas (locale 1) to provide transportation (service 3) produces noise and air pollution (environmental effects 1 and 5) that can be significantly abated by altering the *density* of vegetation near the highway.
3. Improve or maintain the *productivity* of an area. Example: Disposal of wastes (service 1) from residential areas (development 4) in urban rivers (locale 1) pollutes water quality (environmental effect 2). The problem can be alleviated by transporting treated wastes to nearby forest environments and spraying the affluent on the soil, which in turn filters out the nutrients and improves the *productivity* of the forest so that it can continue to act as a natural filtering agent to purify waste water.

4. Rearrange or hold constant *spacial patterns* of vegetation. Example: *Spacial patterns* of vegetation can be arranged so as to enhance the aesthetic quality of flora and fauna (environmental effect 6) at cultural and institutional structures (development 6) designed for recreational activities (service 10) in urban situations (locale 1).

The four constraints just listed relate a given research package (four-way combination of items in table 1) to man-forest interactions. The four-way packages generated specify man's role in these interactions. We incorporated the forest-related aspect by assigning a forestry-related solution constraint to any given package. In this way we filtered from all total possible packages only those packages in which forest-related variables may help solve problems of megalopolitan man.

This procedure for matching environmental forestry-research solutions to four-way combinations of services, locales, developments, and effects corresponds to the way a computer weeds out all the wrong answers until only the right answers are left. The magnitude of such weeding operations in this case dealt with taking the initial 2,160 possible four-way combinations of items and finally accepting only 321 that were meaningful in terms of Pinchot Institute objectives and constraints.

Each of these 321 packages was then assigned either a high or low priority rating, depending on the social-needs urgency for research in that particular package and the research.

To be rated high priority, a package had to meet two criteria:

1. There was an urgent social need for research within the package problem area.
2. There seemed to be a reasonable probability of success for associated research needs.

A low priority was given if a package met only one or none of these two criteria but still was a feasible area for research.

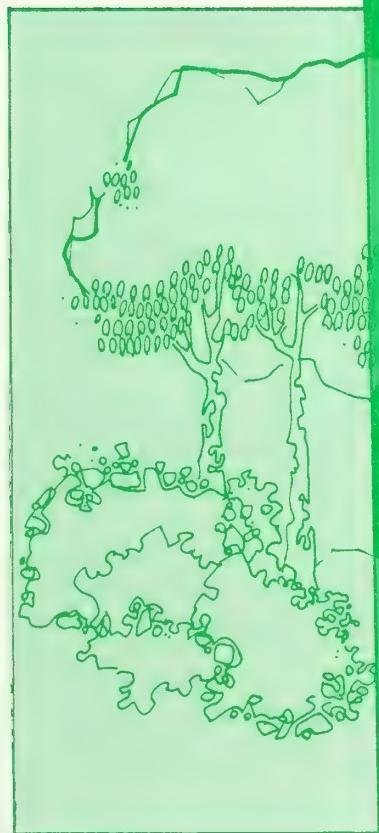
It should be recognized that the decisions made in the weeding and priority assignment were subject to the biases of the multidisciplin-

CHANGE OR
MAINTAIN SPECIES
COMPOSITION

ALTER OR PRESERVE
DENSITY

IMPROVE OR
MAINTAIN
PRODUCTIVITY

REARRANGE OR
HOLD CONSTANT
SPACIAL
PATTERNS



ary team involved. Therefore the packages that were eliminated are not necessarily meaningless, and any user of this system should be prepared to redirect any package that can be rationally proved viable for consideration. However, we believe that it would be rare to find such items in a search of both high- and low-priority items. In fact, low-priority items were retained in the system as a fail-safe insurance against elimination of viable research packages that may be explored in further refinements of the systems.

The procedure for selecting the final 321 packages was conducted partly by hand and partly by programming decision rules in a computer. The output at this stage was a list or catalog of problem packages (table 2). In a computer output display, though we can trace the packages through the entire matrix, it is difficult to see quickly the relationships among large segments of the matrix.

Table 2.—Partial list of acceptable research packages from computer output

Services	Locale	Development	Effect
HEALTH	URBAN	HEAVY	AIR
WATER	URBAN	HEAVY	SOIL
WATER	URBAN	HEAVY	NOISE
RECR	URBAN	HEAVY	NOISE
HEALTH	URBAN	POWER	AIR
ENERGY	URBAN	POWER	NOISE
RECR	URBAN	POWER	NOISE
HOUSING	URBAN	RESID	AIR
HOUSING	URBAN	RESID	NOISE
RECR	URBAN	RESID	NOISE
HOUSING	URBAN	RESID	FLORA
RECR	URBAN	RESID	FLORA
HEALTH	URBAN	RESID	FLORA
RECR	URBAN	RESID	FLORA
HOUSING	URBAN	TRANS	AIR

Our next step was to develop a display system that would enable us to use this information easily.

THREE VIEWPOINTS

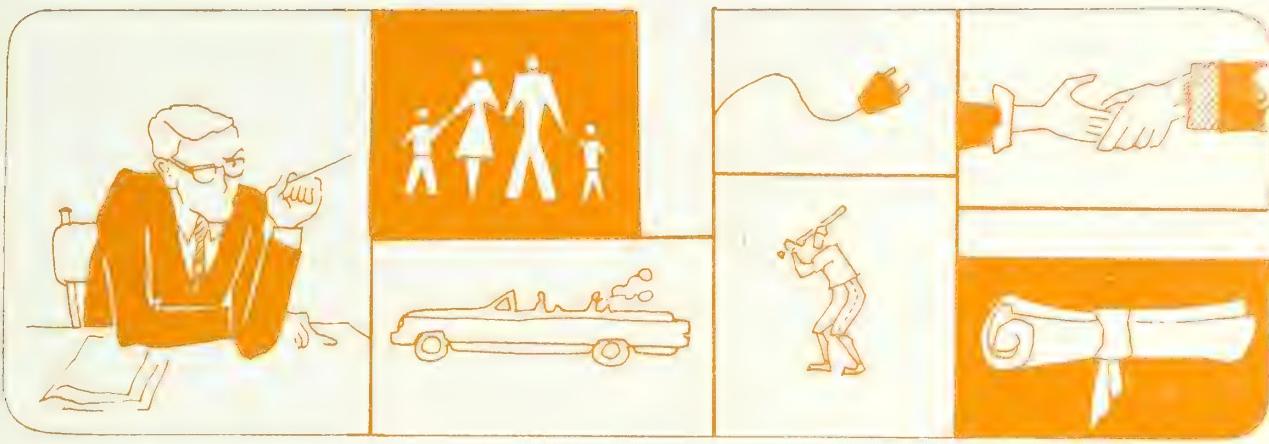
The system we have described was cumbersome to use. It needed to be organized so that complex research problems could be evaluated comprehensively and examined from different viewpoints. Therefore we arranged the 321 packages in three different ways to reflect the following three viewpoints:

1. A social-need viewpoint
2. A supply-response viewpoint

3. An environmental-effect viewpoint

These three perspectives of the system contain exactly the same research packages, both in makeup and in total number, but the packages are grouped differently for each viewpoint. From here on, it is not the individual packages that are important, but how they are interrelated and conceptualized.

SOCIAL — NEEDS VIEWPOINT



First, we can view the system from the standpoint of the policy-maker, decision-maker, or administrator whose primary responsibility is to provide services for urban man's needs. Here our major concern is policy formulation and decision-making about man-environment interactions. Indications of social needs within one or more of the services listed (table 1) include such elements as:

- Land values
- Tax structures
- Access patterns
- Supply and demand trends
- Ownership patterns
- Labor or professional union policies
- Ethnic and cultural values
- Congressional attitude

Past legislation (federal, state, local)
 Interstate regulations
 Regional compacts
 Public opinions and attitudes
 Local ordinances
 Institutional objectives
 Past judicial precedences
 Pending law suits
 Pressure-group actions

By keying first on the services column (table 1), the system can be segmented as shown in figures 1 to 9. Ten services are listed in table 1, but transportation was not included for this particular viewpoint situation.

When the system is portrayed in this manner, the flow through the system can be coded as:

SERVICES ▶ EFFECTS ▶ DEVELOPMENTS ▶ LOCALES

For each social service in figures 1 to 9 the relevant relationships are shown among the service, environmental effect, development,

and locale components of the system where natural vegetation management may ameliorate related adverse environmental effects.

**THE SYSTEM FROM A
SOCIAL-NEED VIEWPOINT**

A given social service appears in the center of each figure. Interrelated environmental effects, technological developments, and locale packages are flowcharted outward from the center by relevant groupings.

Locales shown on the outer rim of each figure are coded as follows:

1. Urban
2. Suburban
3. Exurban
4. Rural

An asterisk identifies high-priority packages. For example, in figure 1 the SERVICE-EFFECT-DEVELOPMENT-LOCALE package labeled 1-2-7-3 is a high-priority package.

ARRANGEMENT OF THE SYSTEM FROM A SOCIAL NEEDS VIEWPOINT

SERVICES REQUIRED BY MAN	ENVIRONMENTAL EFFECTS	TECHNOLOGICAL DEVELOPMENTS USED TO PROVIDE THE SERVICES	LOCES WHERE THE SERVICES ARE PROVIDED
PHYSICAL INFRA-STRUCTURE	<ul style="list-style-type: none">1. AIR QUALITY2. WATER3. SOIL4. TEMPERATURE AND HUMIDITY5. NOISE6. FLORA & FAUNA7. TRANSPORTATION8. ENERGY PROVISION9. HOUSING10. FLOOD CONTROL11. RECREATIONAL STRUCTURES	<ul style="list-style-type: none">1. HEAVY INDUSTRY2. LIGHT INDUSTRY3. POWER4. RESIDENCES5. TRANSPORTATION6. CULTURAL AND INSTITUTIONAL STRUCTURES7. FORESTRY8. AGRICULTURE9. MINING	<ul style="list-style-type: none">1. URBAN2. SUBURBAN3. EXURBAN4. RURAL
INSTITUTIONAL INFRA-STRUCTURE		<ul style="list-style-type: none">12. EDUCATION13. EMPLOYMENT14. HEALTH & WELFARE15. RECREATIONAL ACTIVITY	

FIGURE I

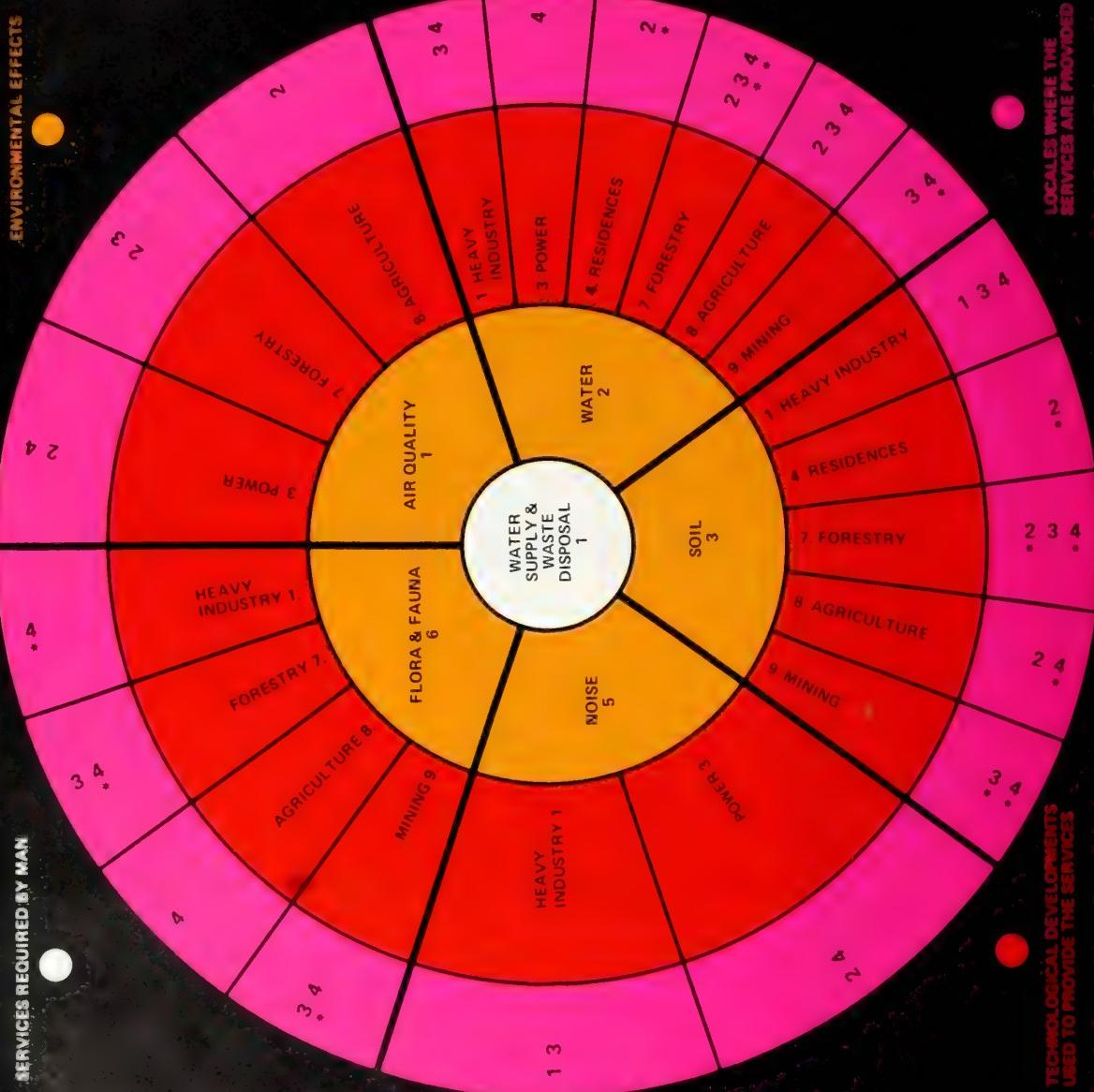


FIGURE 2

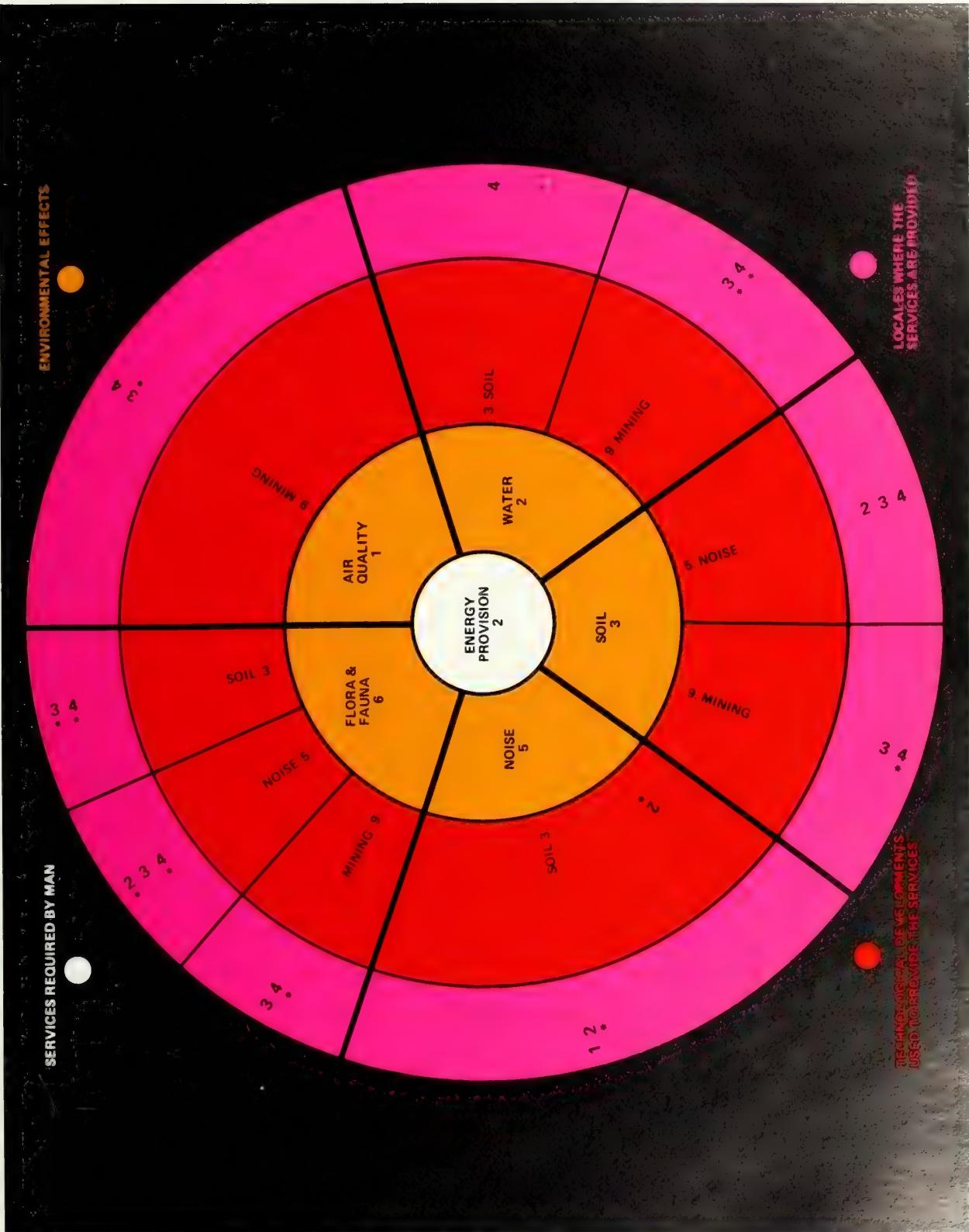


FIGURE 3

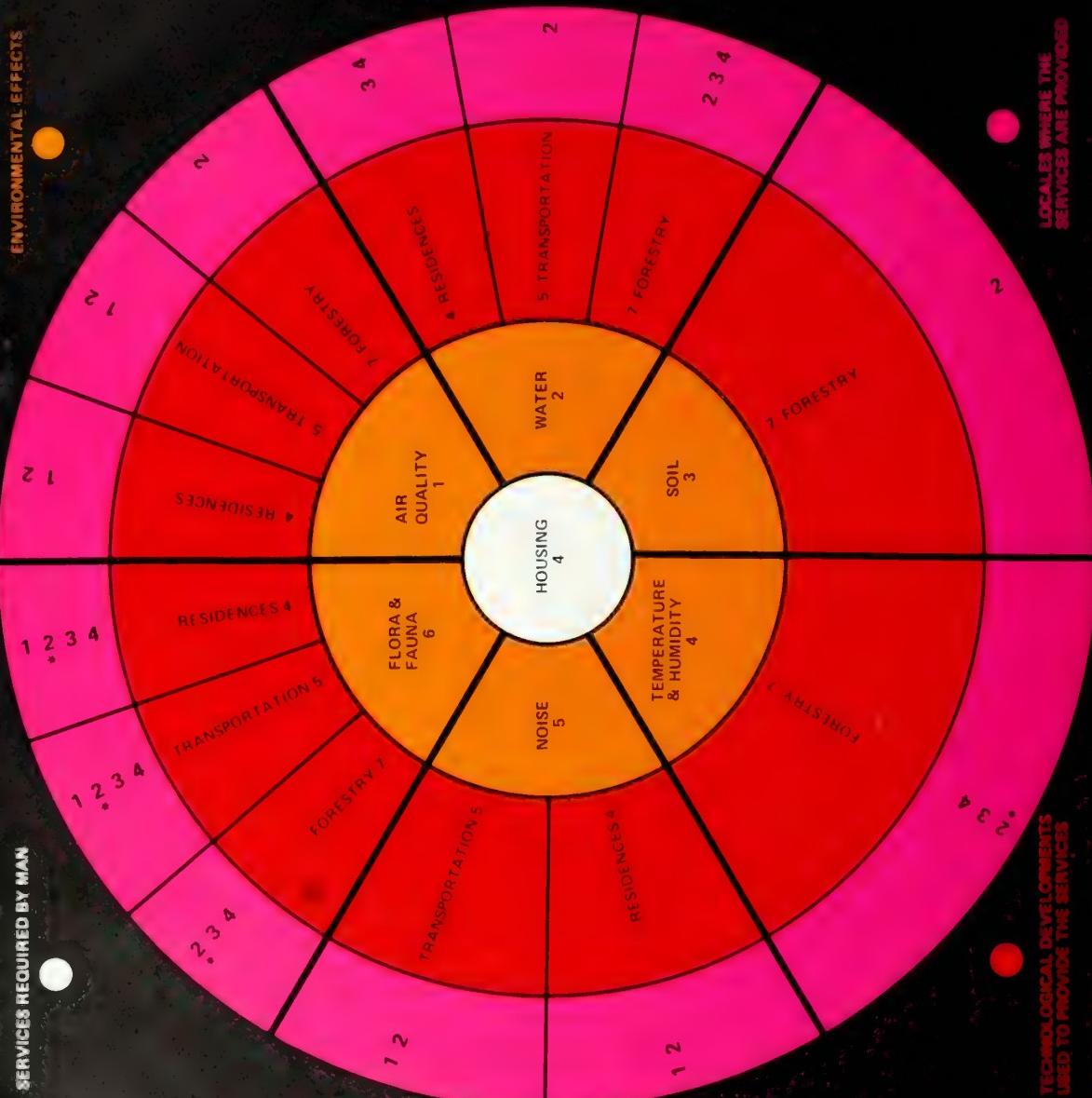


FIGURE 6

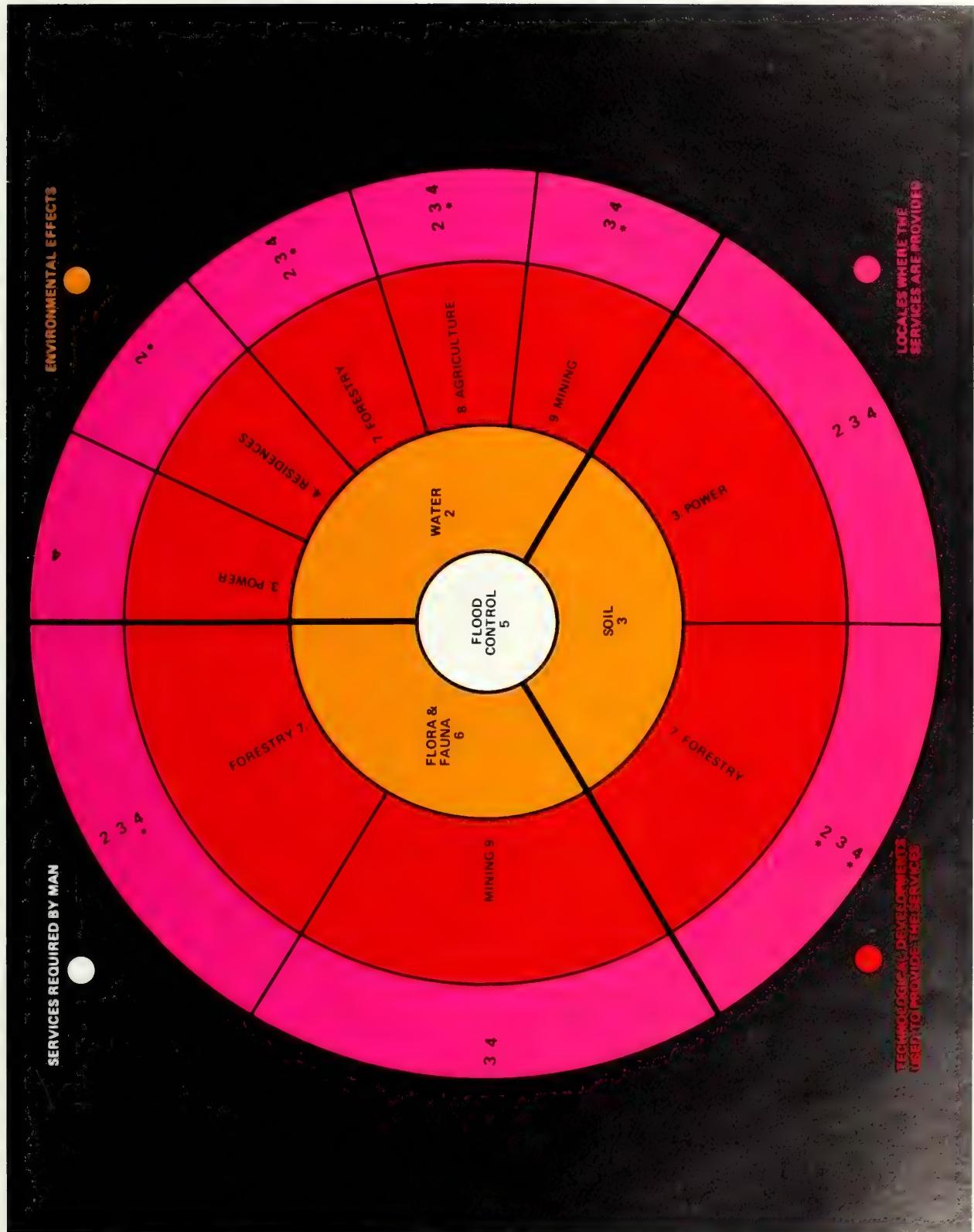


FIGURE 5

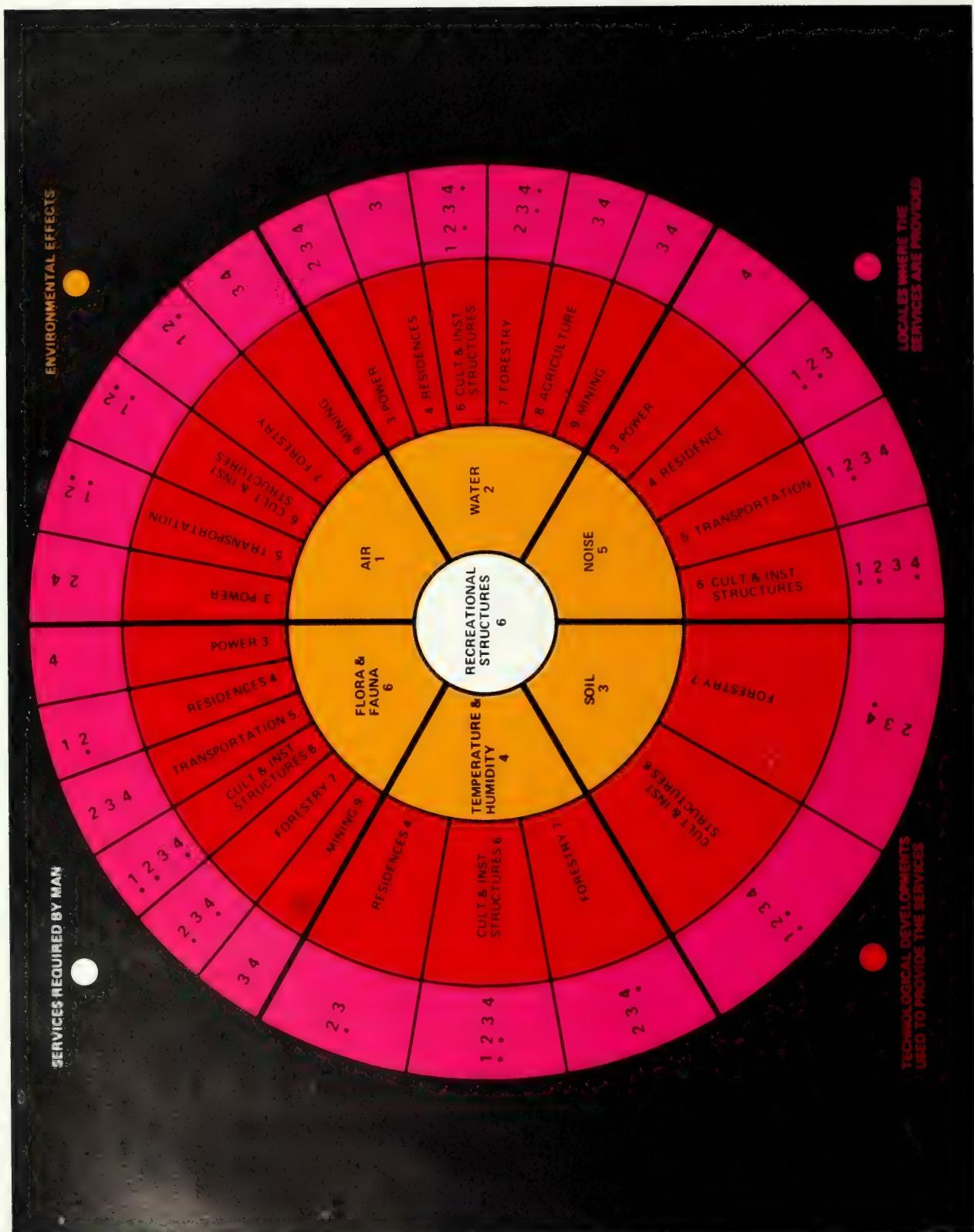


FIGURE 6

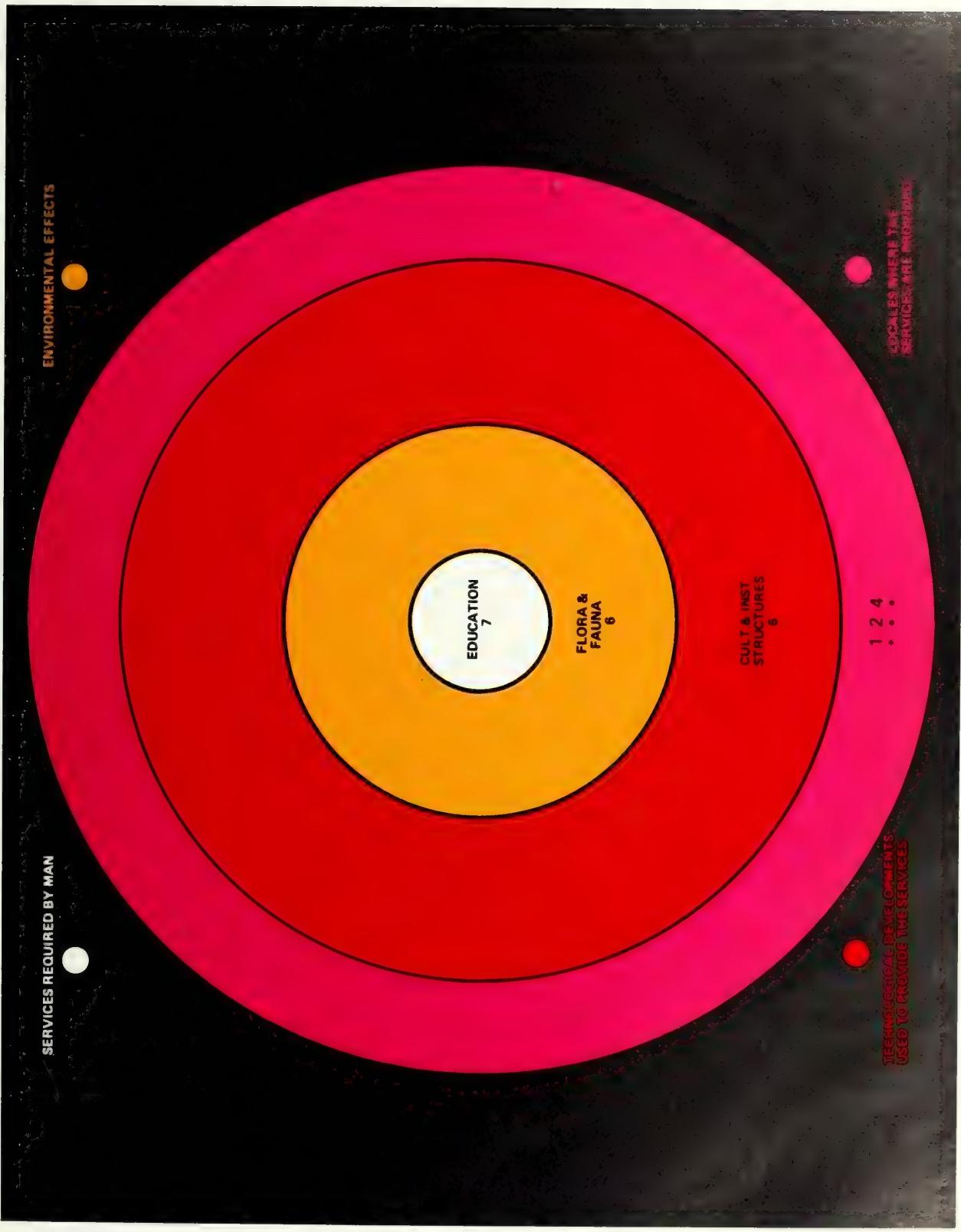


FIGURE 7

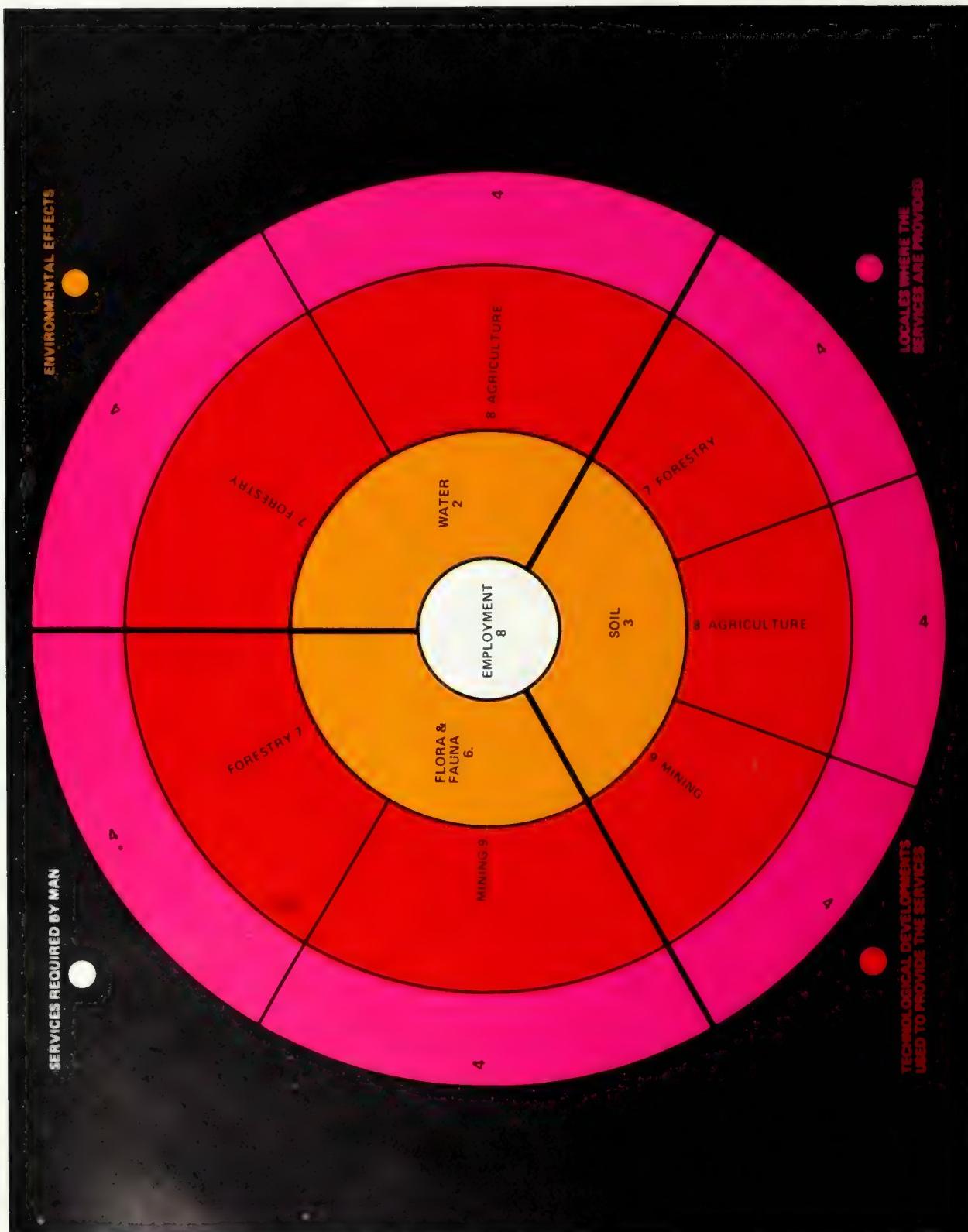


FIGURE 8

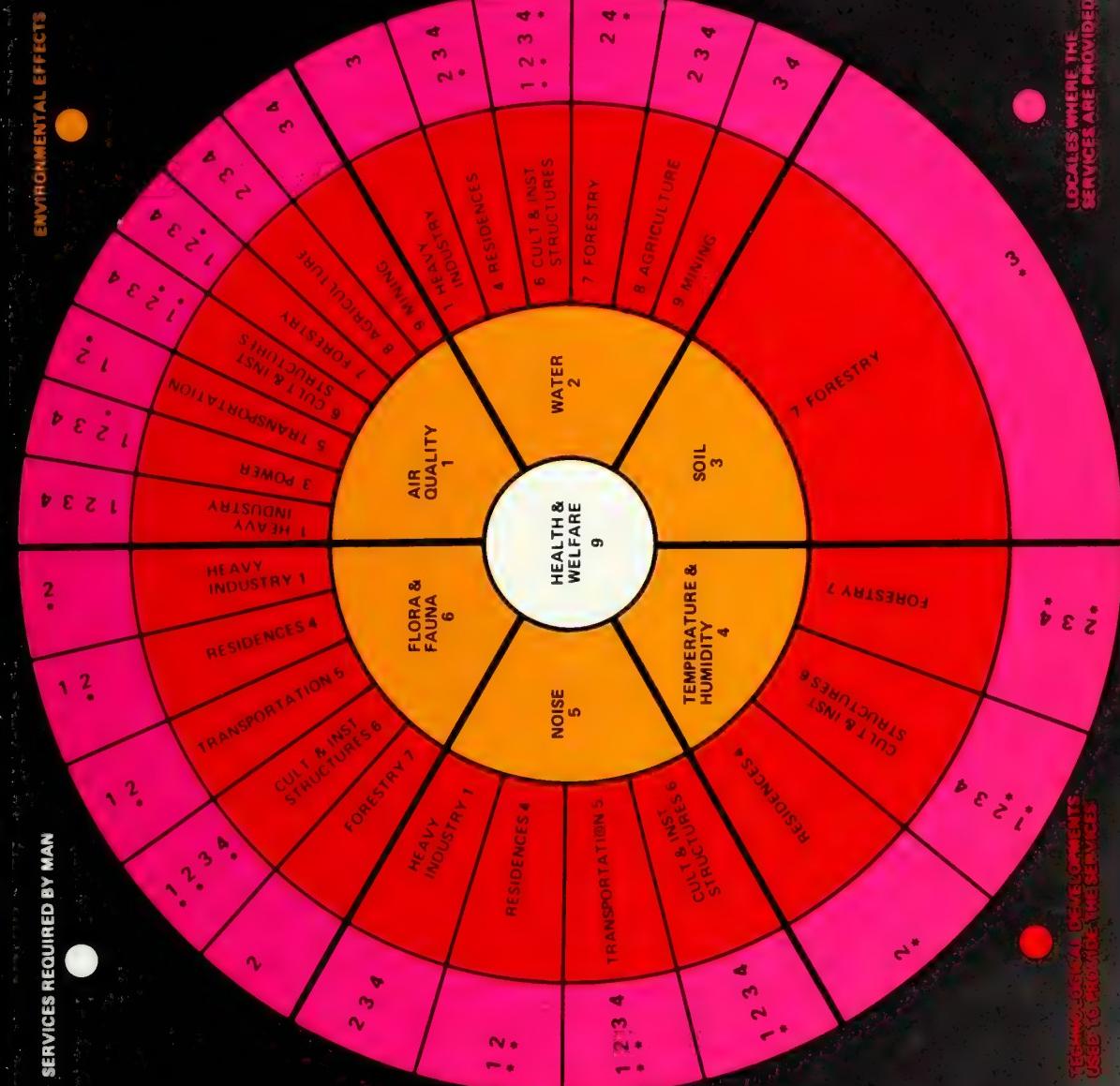
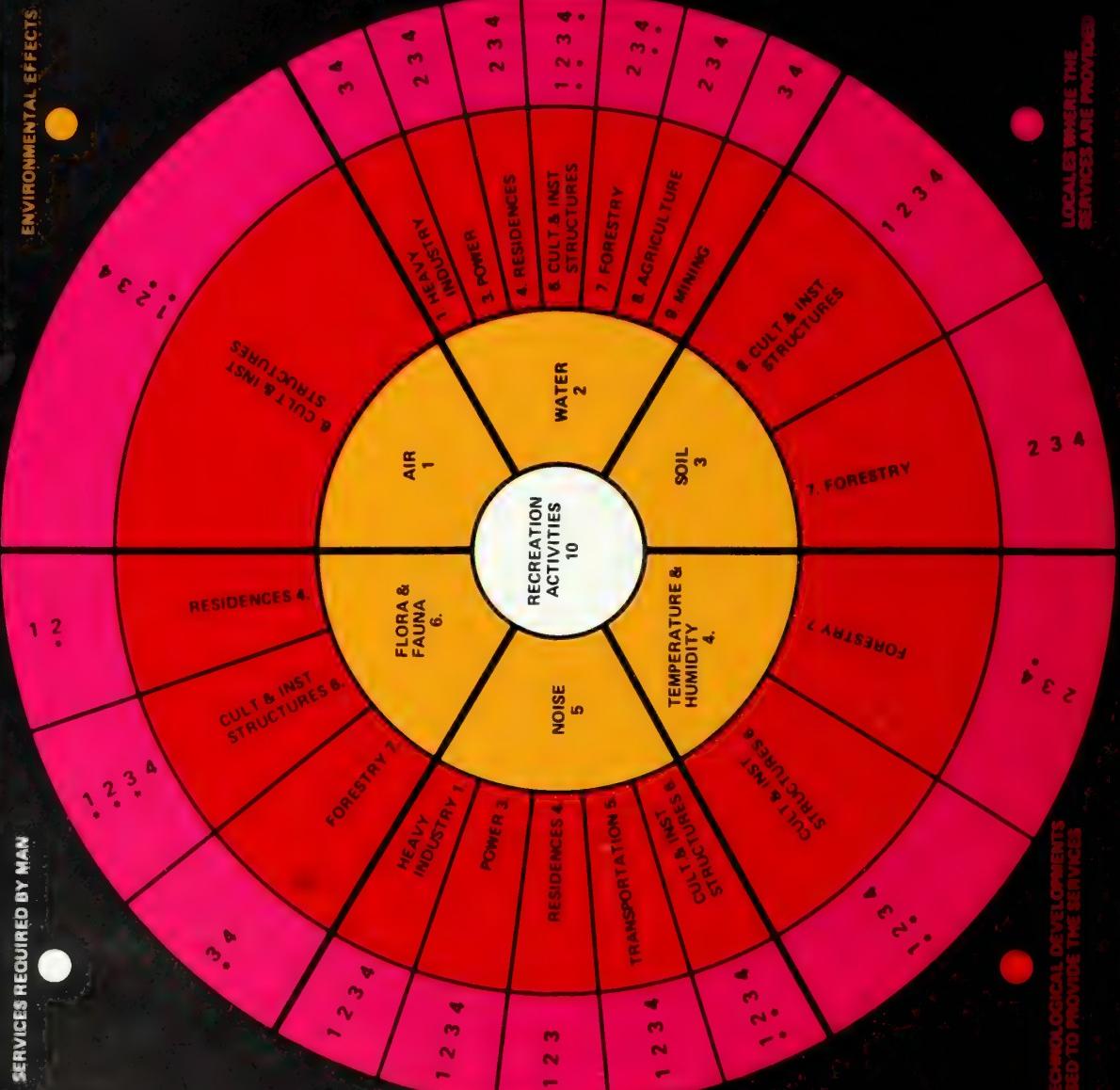


FIGURE 9



SUPPLY — RESPONSE VIEWPOINT



Second, the system can be seen from the perspective of the technologist, planner, industrialist, or engineer who must supply man's services through technological developments. This area of interest involves an assessment of the effects of present and future technology on various environmental forestry situations; in other words, measuring the impact of man on his environment.

Examples of major concern within the various development categories (table 1) includes:

- Oil refining
- Mineral processing
- Pulp and paper manufacturing
- Retail outlets
- Shopping centers and malls
- Fossil-fuel electric plants
- Nuclear power plants
- Apartment complexes

- Condominiums
- Single-family dwellings
- Super highways
- Other highways
- Airports
- Sidewalks
- Right-of-ways for pipelines, powerlines, and telephones
- Elementary and secondary schools
- Colleges and universities
- Parks
- Cemeteries
- Public and private land holdings
- Farms
- Strip-mining

When a supply-response point of view is of major interest, the system can be broken into figures 10 to 17 by starting initially with the developments column in table 1. The system flow in this case can be coded:

DEVELOPMENTS ► EFFECTS ► SERVICES ► LOCALES

Developments begin the flow, and they are subdivided by environmental effects, services, and finally location. For each development in figures 10 to 17, relevant relationships among

environmental effects and developments in particular locations are shown where natural vegetation management may ameliorate adverse environmental effects.

THE SYSTEM FROM A SUPPLY-RESPONSE VIEWPOINT

A given technological development appears in the center of each figure. Interrelated environmental effects, social services, and locale packages are flowcharted outward from the center by relevant groupings.

Locales shown on the outer rim of each figure are coded as follows:

1. Urban
 2. Suburban
 3. Exurban
 4. Rural
- An asterisk identifies high-priority packages. For example, in figure 11 the DEVELOPMENT-EFFECT-SERVICE-LOCALE package labeled 3-5-2-2 is a high-priority package.

ARRANGEMENT OF THE SYSTEM FROM A SUPPLY RESPONSE VIEWPOINT

TECHNOLOGICAL
DEVELOPMENTS USED TO
PROVIDE THE SERVICES

ENVIRONMENTAL
EFFECTS

SERVICES REQUIRED
BY MAN

LOCALES WHERE THE
SERVICES ARE
PROVIDED

1. HEAVY INDUSTRY
2. LIGHT INDUSTRY
3. POWER
4. RESIDENCES
5. TRANSPORTATION
6. CULTURAL AND
INSTITUTIONAL
STRUCTURES
7. FORESTRY
8. AGRICULTURE
9. MINING

1. AIR QUALITY
2. WATER
3. SOIL
4. TEMPERATURE
AND
HUMIDITY
5. NOISE
6. FLORA &
FAUNA

PHYSICAL
INFRA-STRUCTURE

1. URBAN
2. SUBURBAN
3. EXURBAN
4. RURAL

INSTITUTIONAL
INFRA-STRUCTURE

1. EDUCATION
2. EMPLOYMENT
3. HEALTH &
WELFARE
4. RECREATIONAL
ACTIVITY

FIGURE 10

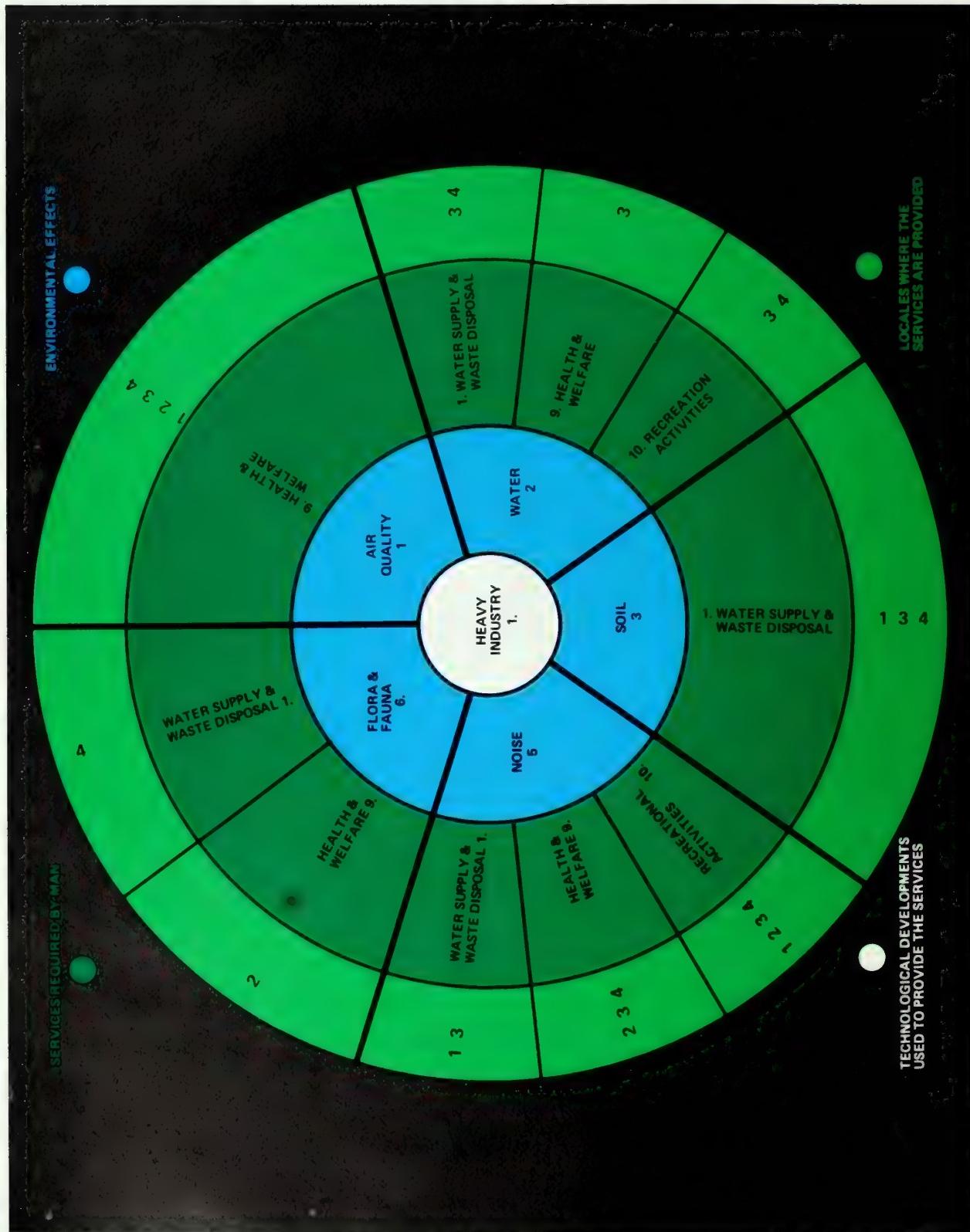


FIGURE II

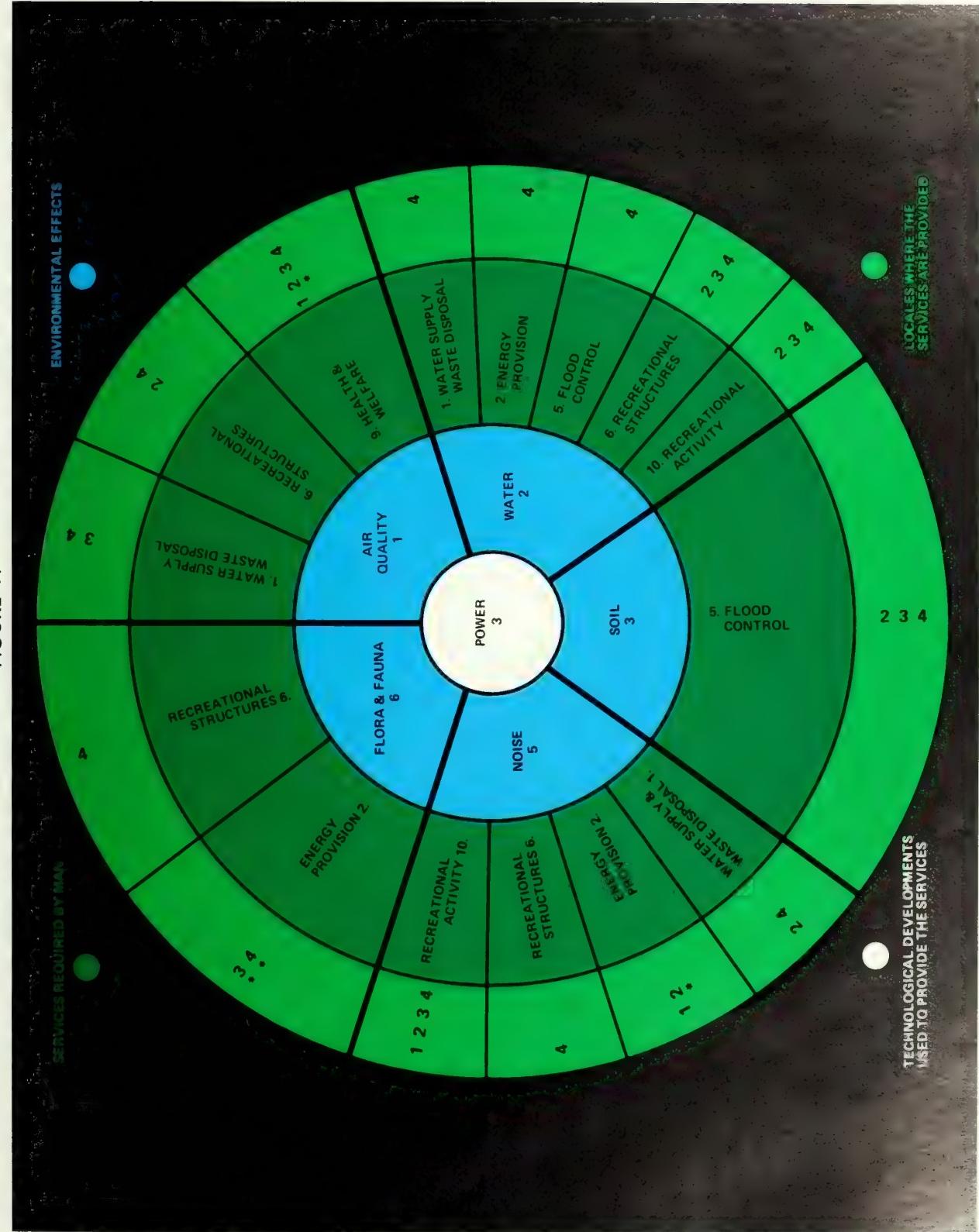


FIGURE 12

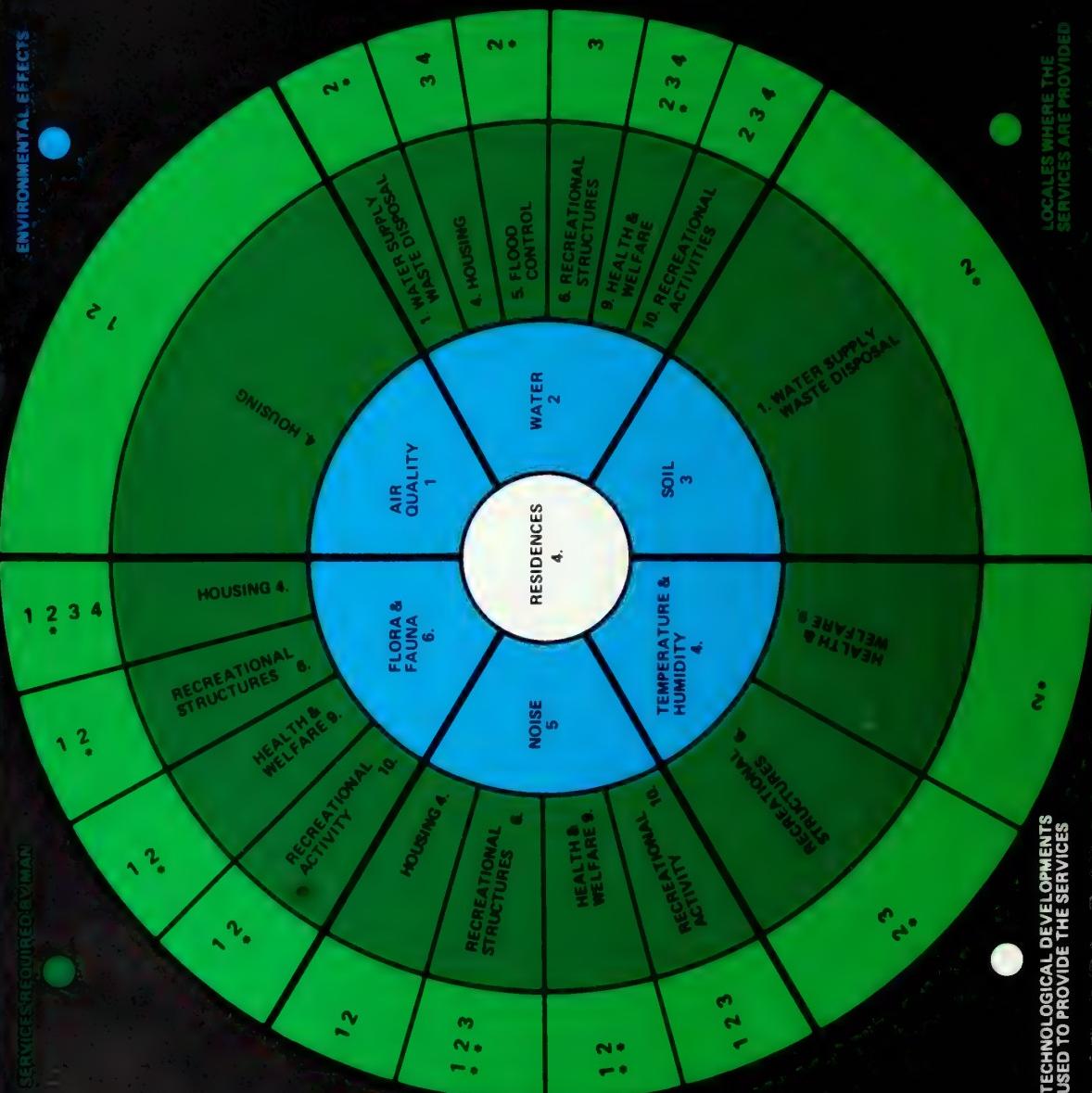


FIGURE 13

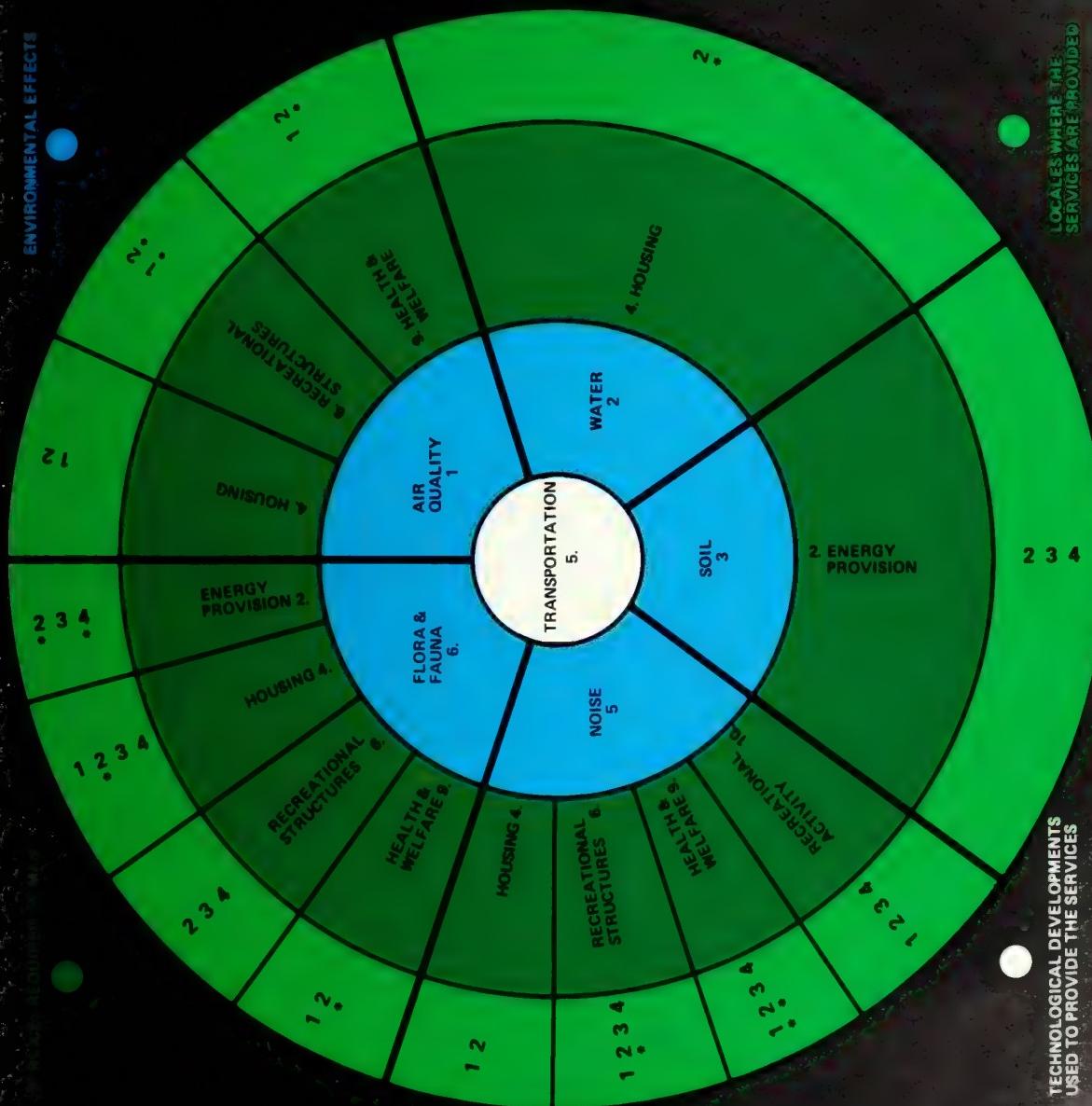


FIGURE 14

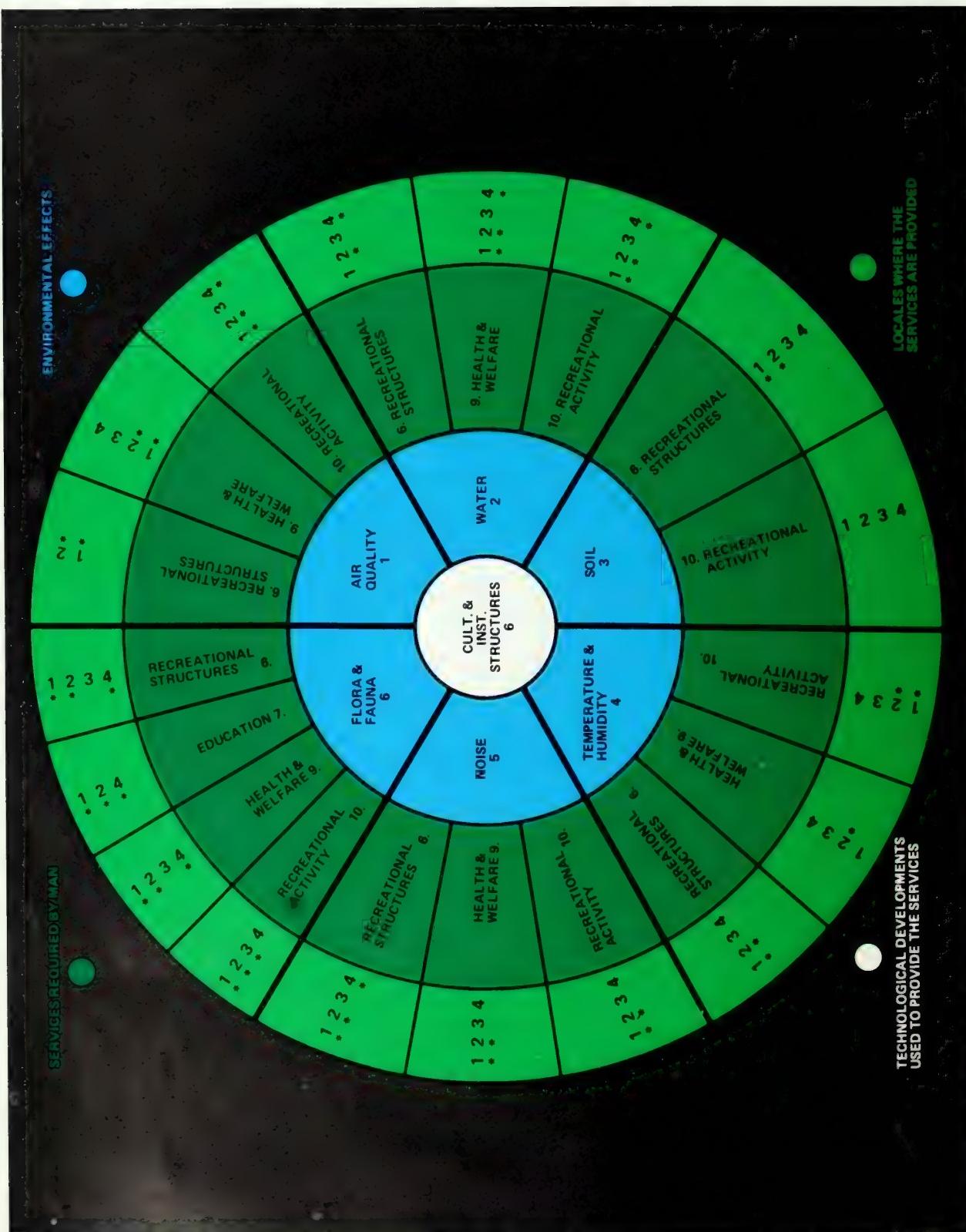


FIGURE 15

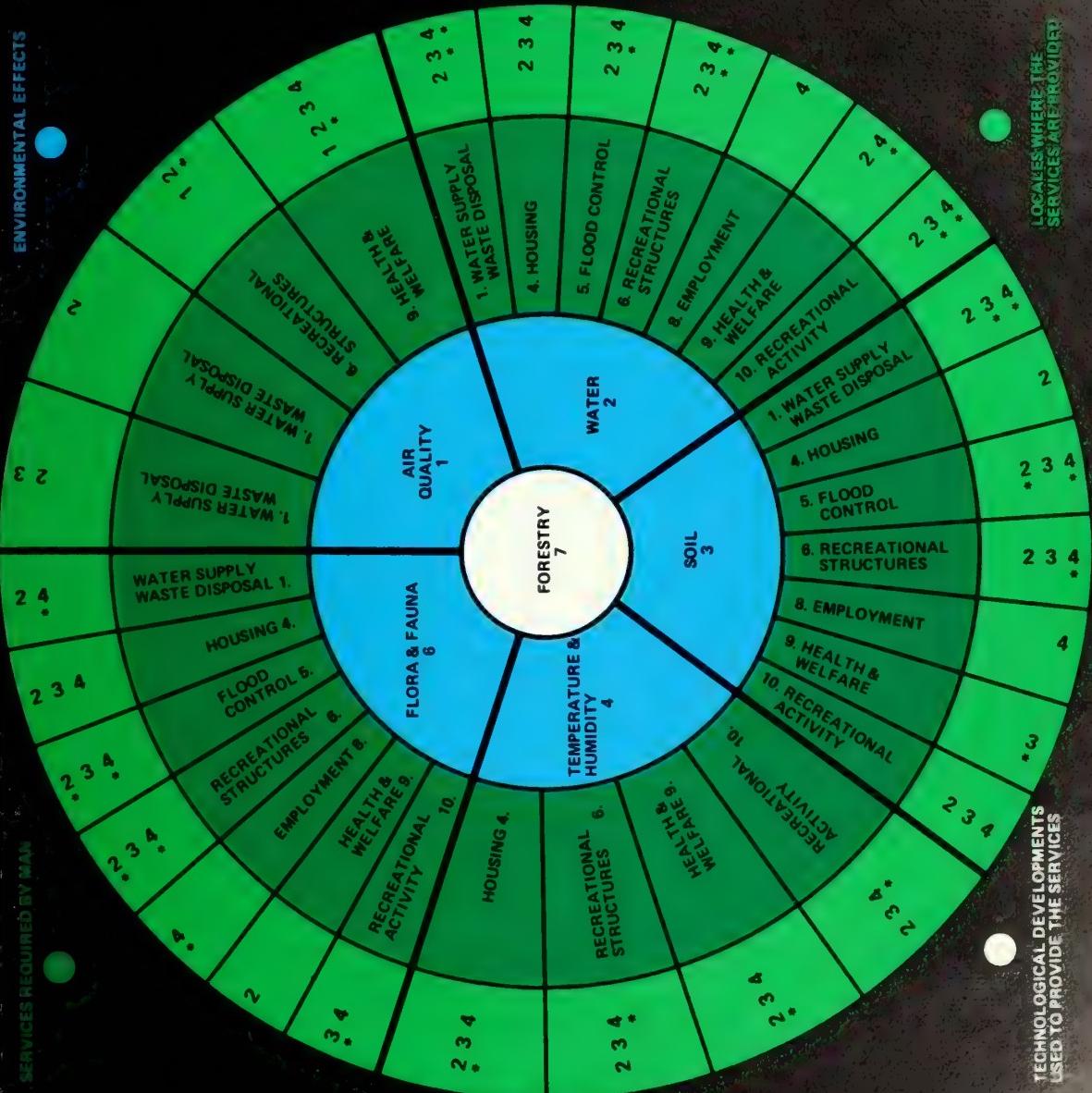


FIGURE 16

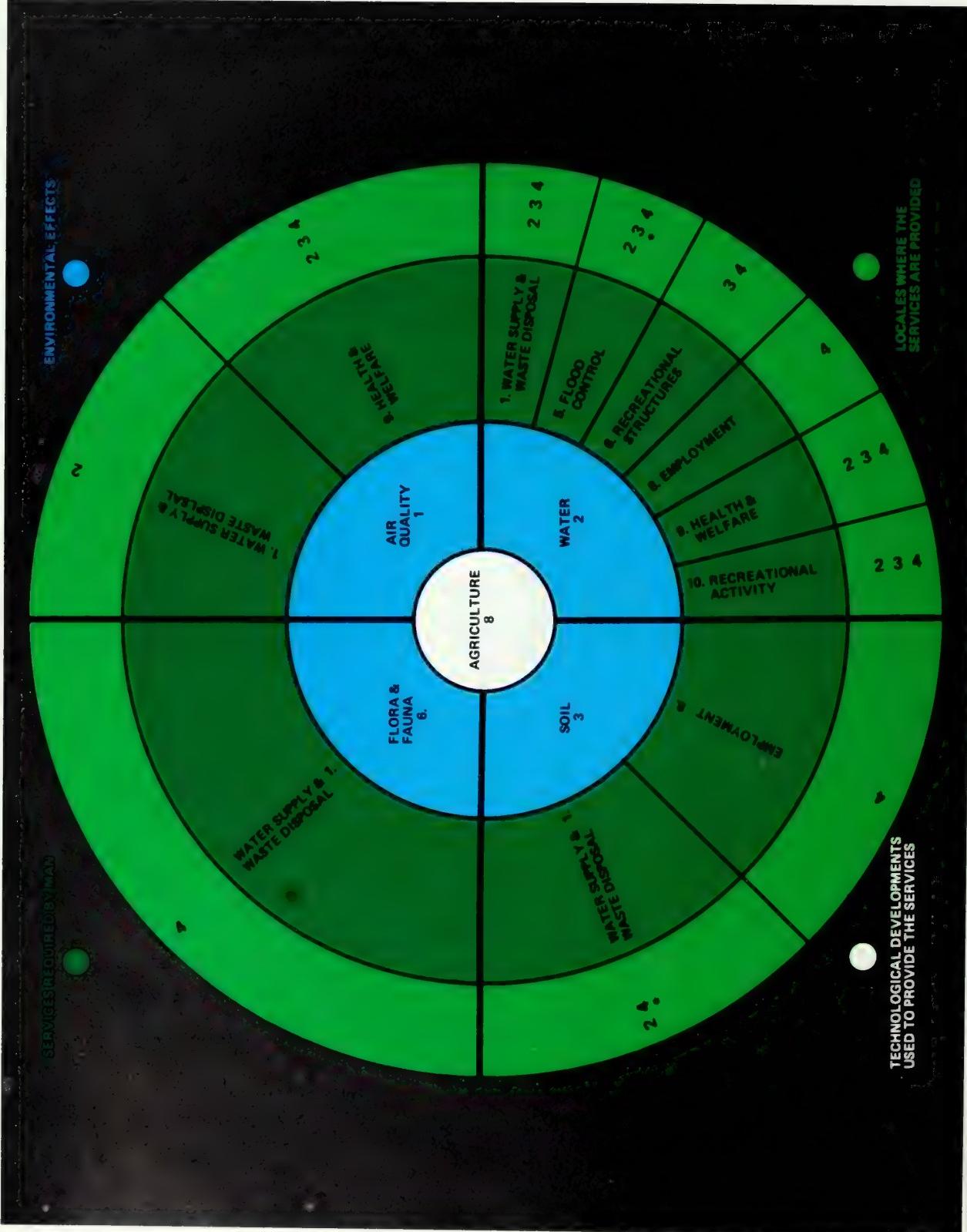
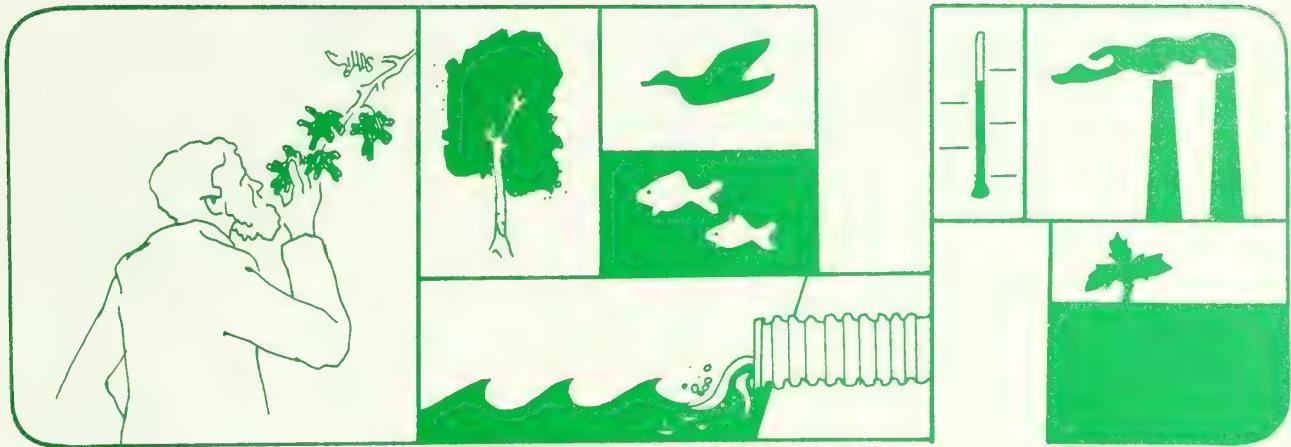


FIGURE 17



ENVIRONMENTAL – EFFECTS VIEWPOINT



And finally, the system can be examined from a research-administration perspective or from the viewpoint of the ecologist who is interested primarily in assessing the impact of the environment on man. Associated with one or more of the environmental effects listed in table 1 are such elements as:

- Chemical properties
- Mechanical properties
- Particulate matter
- Odor
- Stability
- Color
- Micro-organism counts
- Water-holding capacity
- Rate of flow
- Turbidity
- Relative humidity
- Precipitation
- Wind speed
- Macroclimate
- Microclimate

Decibel reduction capabilities
Overstory density
Understory density
Mammals
Birds
Insects

Various combinations of all environmental effects contribute to the aesthetic quality of an environment. For this reason, aesthetic quality was not listed as an individual item in table 1. We assumed that the aesthetic quality of an environment results from a composite effect of various components throughout the environmental factors listed under environmental effects. Aesthetic quality needs to be considered in any given combination of the four components of the system.

From the environmental-effect viewpoint, we key first on the environmental-effect column of table 1, and separate the system into six figures, 18 to 23. The system flow in these figures is coded:

EFFECTS ▶ SERVICES ▶ DEVELOPMENTS ▶ LOCALES

Environmental effects are subdivided by services, developments, and finally by locale.

THE SYSTEM FROM AN ENVIRONMENT-EFFECT VIEWPOINT

A given environmental effect appears in the center of each figure. Interrelated social services, technological developments, and locale packages are flowcharted outward from the center by relevant groupings.

1. Urban
2. Suburban
3. Exurban
4. Rural

An asterisk identifies high-priority packages. For example, in figure 18 the EFFECT-SER-VICE-DEVELOPMENT-LOCALE package labeled 1-2-9-3 is a high-priority package.

Locales shown on the outer rim of each figure are coded as follows:

ARRANGEMENT OF THE SYSTEM FROM A ENVIRONMENTAL EFFECTS VIEWPOINT

ENVIRONMENTAL EFFECTS
SERVICES REQUIRED BY MAN
TECHNOLOGICAL DEVELOPMENTS USED TO PROVIDE THE SERVICES

LOCES WHERE THE SERVICES ARE PROVIDED

1. AIR QUALITY
2. WATER
3. SOIL
4. TEMPERATURE AND HUMIDITY
5. NOISE
6. FLORA & FAUNA

PHYSICAL INFRA-STRUCTURE

1. WATER SUPPLY & WASTE DISPOSAL
2. ENERGY PROVISION
3. TRANSPORTATION
4. HOUSING
5. FLOOD CONTROL
6. RECREATIONAL STRUCTURES

INSTITUTIONAL INFRA-STRUCTURE

7. EDUCATION
8. EMPLOYMENT
9. HEALTH & WELFARE
10. RECREATIONAL ACTIVITY

1. HEAVY INDUSTRY
2. LIGHT INDUSTRY
3. POWER
4. RESIDENCES
5. TRANSPORTATION
6. CULTURAL AND INSTITUTIONAL STRUCTURES
7. FORESTRY
8. AGRICULTURE
9. MINING

1. URBAN
2. SUBURBAN
3. EXURBAN
4. RURAL

FIGURE 18

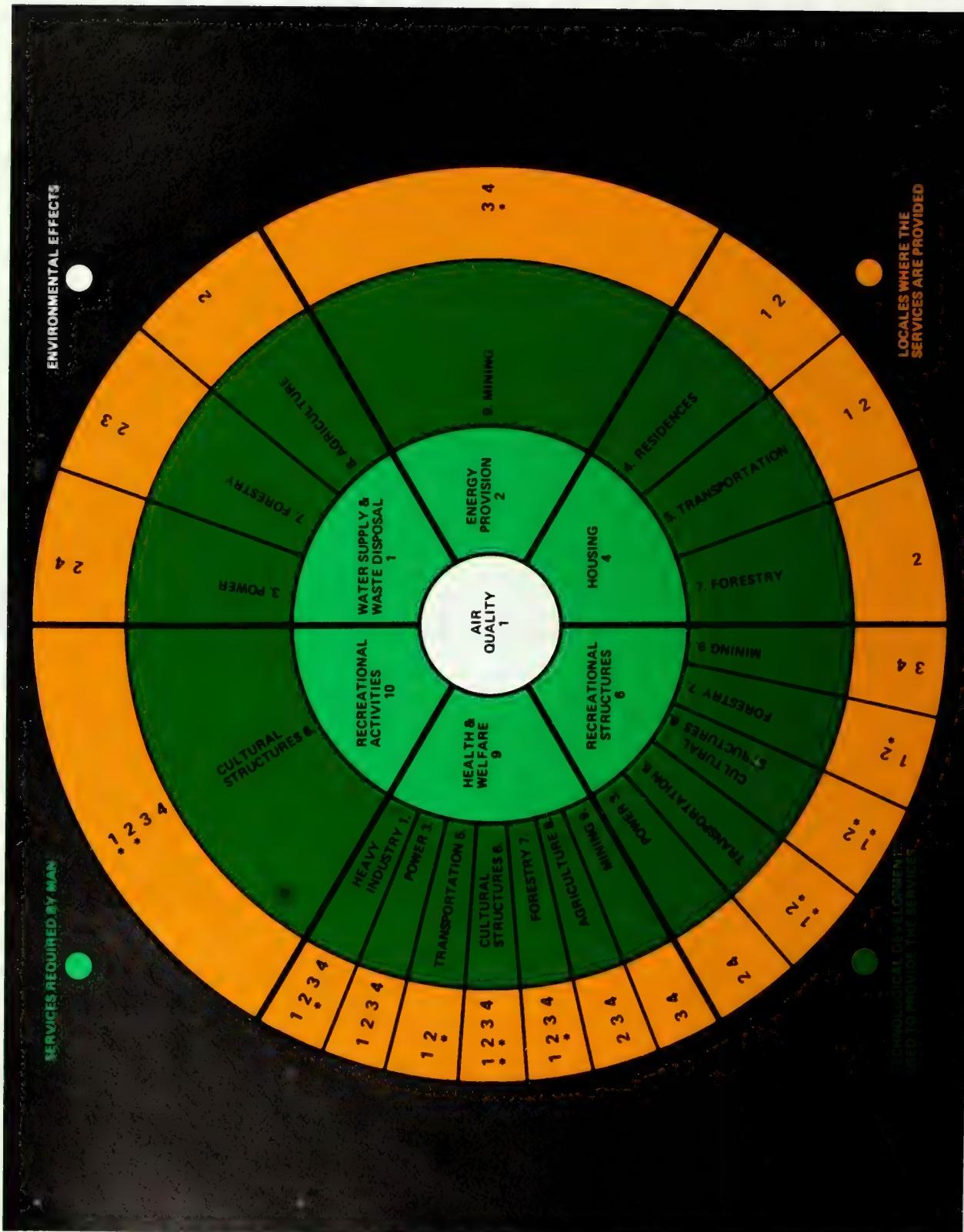


FIGURE 19



FIGURE 20



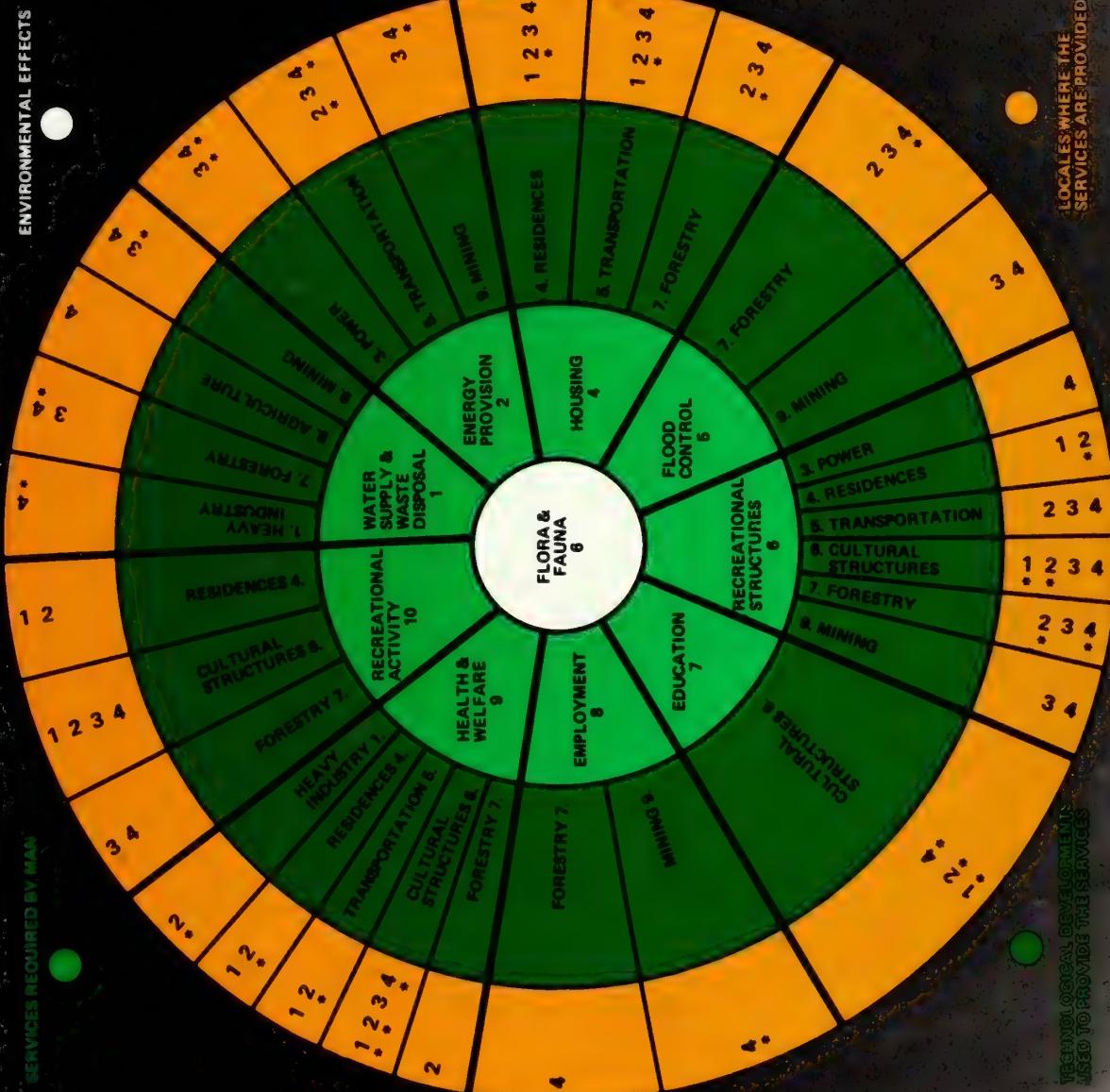
FIGURE 21



FIGURE 22



FIGURE 23



SYSTEM FLEXIBILITY

Packaging Research to Meet Each Viewpoint

The overall system can be segmented in various ways to make complete scientific packages that answer a wide range of objectives, depending on the type of decision-maker involved. We may package scientific work along functional research lines; for example, a complete package for water-quality research. We may package scientific work along engineering lines; for example, a complete package for residential developments. We may package scientific work along service lines; for example, a complete package for water-supply and waste-disposal policies.

Traditionally, our research has been organized into discrete scientific fields or disciplines that can be pigeonholed according to parts of the system flow outlined in the environmental-effect viewpoint. The objective of such research has been to dig deeply within a narrow field of study. The environmental-effect viewpoint stresses this objective. It suggests research possibilities within a narrow segment of the total system and enables us to:

1. Evaluate a research study proposal in the context of the total needs within a specific functional or scientific area.
2. Develop a research program in a functional area that will provide input information to the social-needs and supply-response systems.

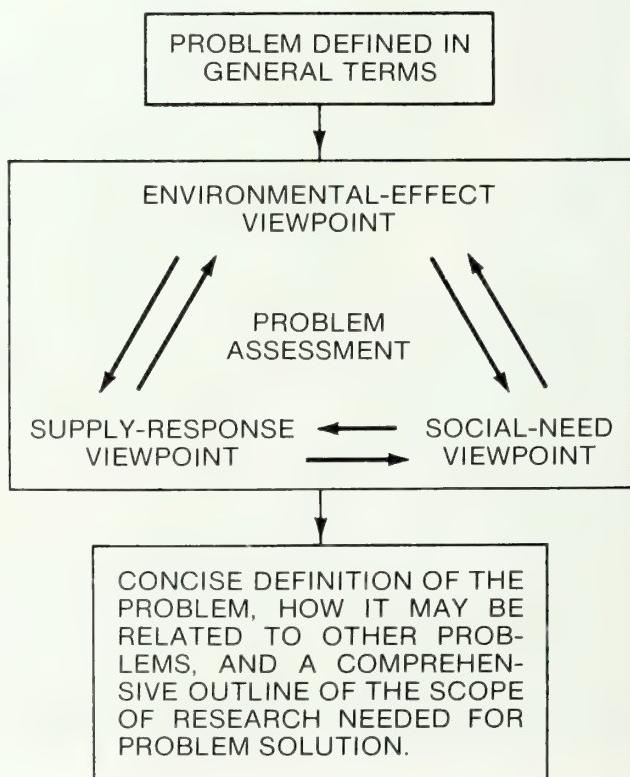
By bringing the social-need and supply-response viewpoints to bear on a given environmental problem, we can evaluate that problem from the position of the decision-maker who is responsible for providing associated social needs or technological developments. Faced with a contemplated development project or program, for example, decision-makers themselves can begin to evaluate resulting environmental effects by looking at the system from their own point of view. Such examinations can provide:

1. An appraisal of the technology involved.
2. An outline of the research required to measure the primary and secondary effect of such technology on natural ecosystems.

3. A relevant outline for preparing an environmental impact statement concerning that same technology.
4. An improved understanding of environmental systems.
5. Knowledge required to permit more effective efforts to prevent environmental degradation.
6. A means through research to accommodate man's activities to environmental constraints.

From their own viewpoints of the system, decision-makers can define the research information input they need. Then, by referring to the environmental-effect viewpoint of the system, these same decision-makers can evaluate a research proposal or suggest what kind of research is needed in terms of their own immediate requirements.

Thus we can generate and reinforce the information required to comprehensively attack a given problem when that problem is subjected to all three viewpoints in this way:



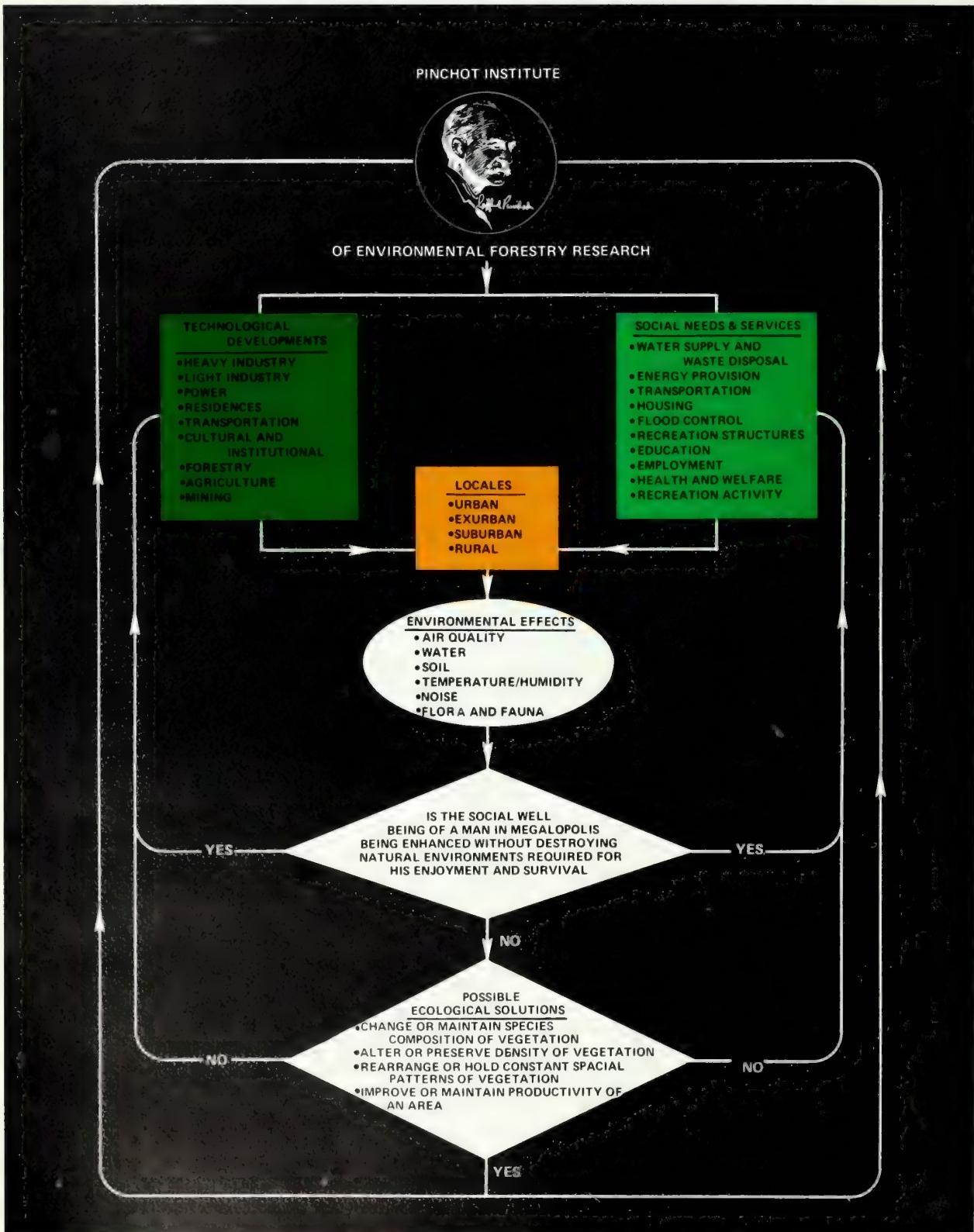
However, in the final analysis of any given problem, the effects of the social and supply innovations will be determined not by the extent to which man can manipulate the external world but by the limitations of the ecosystem (or environmental-effect viewpoint). The ecosystem constraints set the sideboards for the ultimate solution to any given problem. Only in this way will the research approach provide answers that insure the proper functioning of natural ecosystem required for man's ultimate survival in and around Megalopolis.

Who, What, Where, When, Why, and How?

The six questions (who? what? where? when? why? and how?) about research are often difficult to answer explicitly. This system, however packaged, should make answering them easier. The environmental-effects and services components taken together broadly answer the question *what*. The development and locale segments taken together broadly answer *where*. Answers to these two questions go a long way toward determining *how* to conduct the research, although much of the *how* sometimes must (and should) be left to the researcher's ingenuity. Use of the system to indicate relevant combinations shows *why* the work is important. We already know the scientist is going to do the work, and the research administrator says *when*.



A DIAGRAM OF THE ENTIRE SYSTEM



HOW THE SYSTEM WORKS

An Environmental-Effect Approach

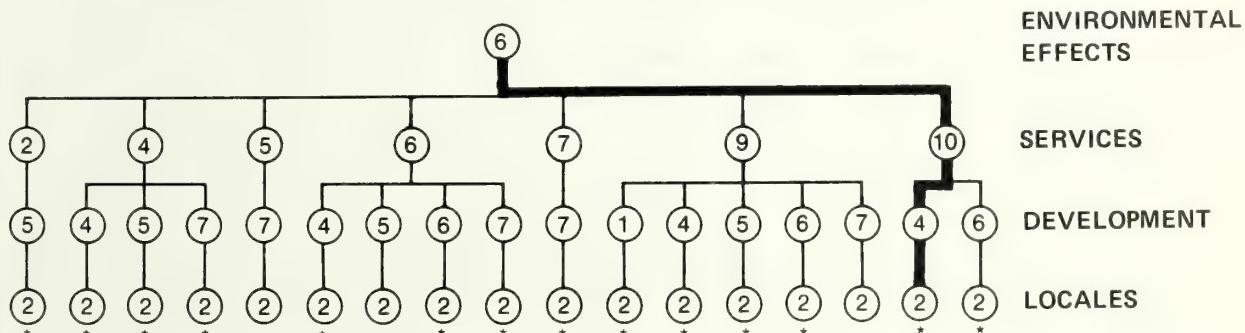
Use of the packages will be illustrated by example, and in this example our primary package will be formulated from the environmental-effect viewpoint. We begin by assuming that a specific research proposal is made to a research administrator, and we trace the administrator's evaluation of the proposal with reference to the complete catalogue of studies in the general area of interest for a specific environmental effect. (The example is kept very simple here simply to illustrate the procedure.)

A scientist proposes studying vegetation manipulation in housing developments in suburban areas so that the results of his research can be used where residents can enjoy certain songbirds and wild animals in suburbia. (Songbirds, incidentally, are also an extremely important factor in natural ecosystems related to man's health and wellbeing.)

Wildlife habitat (flora-fauna) is the central issue here, so we go first to the environmental-effect viewpoint figures, select figure 23 (flora and fauna), and code the research proposal as 6-10-4-2:

Environmental Effect (flora-fauna)	Service (recreation activity)	Development (residences)	Locale (suburban)
6	10	4	2

To place the research proposal in perspective, we chart all other flora and fauna effects in figure 23 that are relevant to suburbia (locale 2). We examine the interconnected parts of figure 23 that are relevant to the environmental effect stipulated in the proposed study. Those parts of that system are:



The number in each circle follows the numbering code for effects, services, developments, and locales found in table 1. An asterisk along the bottom line of numbers indicates a high-priority package. The original proposal in the flow chart is indicated by a heavy line. All other possibilities are shown by light lines.

By evaluating the research proposal in this way, we begin to see how it relates to a complete research program for flora and fauna effects in a suburban setting. By inspection, conclusions can be reached on several important points regarding how the study is related to overall Pinchot Institute objectives:

1. It is in a high-priority package category.
2. It is part of a group of 17 relevant packages or study areas—of which 14 are high-priority packages.
3. Seven suburban services are involved in the total subsystem—services 2, 4, 5, 6, 7, 9, and 10 (table 1).
4. Five developments in suburbs are involved in the total subsystem—developments 1, 4, 5, 6, and 7 (table 1).

For evaluation of a study proposal by a research administrator—and depending upon the ability, qualifications, and experience of the

scientist—one of several recommendations is likely:

1. The proposal is accepted and funded.
2. The proposal is expanded to include other services, such as 4, 6, and 9 as well as 10.
3. The proposal is included in a larger study designed to encompass all 17 relevant study areas.

Recommendation 3 is tantamount to a program-development charge; the research administrator has made a program-development analysis from the flow chart and indicates what to include and where to do it. The first step in program evaluation is taken.

Next, a senior scientist should make an analysis of the problems within the program to determine what information is already known and what needs further research.

A Social-Need Approach

Now consider a research problem from the social-need response viewpoint. For example, a

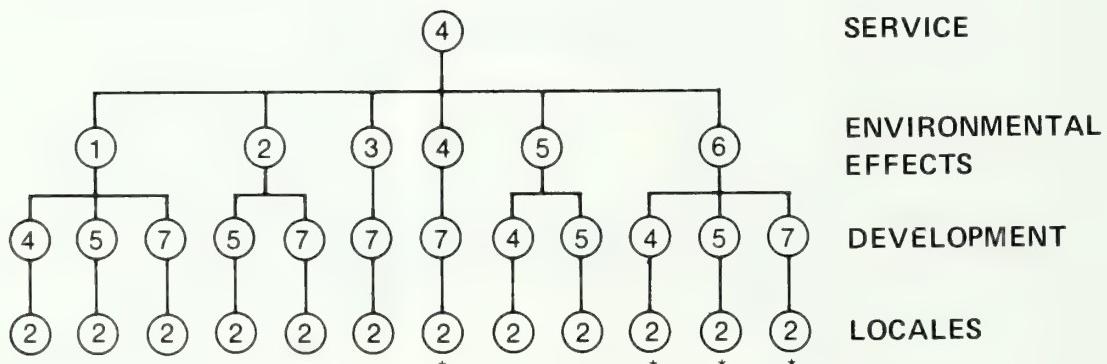
research question from this perspective could be:

In the course of legislating housing needs (service 4) for suburban areas (locale 2), what environmental effects will we encounter that may be ameliorated or protected through policies and programs governing vegetation management? What form of environmental forestry research is needed to develop relevant information for developing policy to regulate housing?

The package code at this point has only two numbers, one for services and one for locales:

Services (housing)	Effects	Developments	Locales (suburban)
4	?	?	2

The missing parts of the package must be supplied to develop a research program. In figure 3, social need number 4 (housing) is selected and traced through the paths (or subsystem) where the two codes (4 and 2) exist. Those parts of that system are:



The number in each circle follows the number system for services effects, developments, and locales found in table 1. An asterisk along the bottom line of numbers indicates a high-priority package.

Therefore, by filling in the missing code numbers so that all the relations can be traced, development of the program proposal for housing in suburbia has begun. Now we can recognize what environmental factors are relevant in this context and what developments they are related to:

1. Research capability in all six environmental categories in this program must be developed.
2. Only three developmental-viewpoint situations are likely to be encountered:
 - a. Residence (4) under three environmental effects areas.
 - b. Transportation (5) under four environmental effects areas.
 - c. Forestry (7) under six environmental effects areas.

3. About one-third of the indicated study areas are high priority.

Thus, as in the previous example, the problem dimensions are defined and the relative complexity is determined—clear avenues to problem selections and analysis. The research administrator interested in addressing the enhanced problem package has a point of beginning for determining the expertise and funding needed.

A Supply-Response Approach

In a traditional sense, the importance one should attach to evaluating a given problem in the above manner depends upon the responsibilities of the one making the appraisal. A suburban real-estate developer, using the previous example, has an outline on which to base an environmental impact statement, or on which to make an engineering evaluation of technical alternatives.

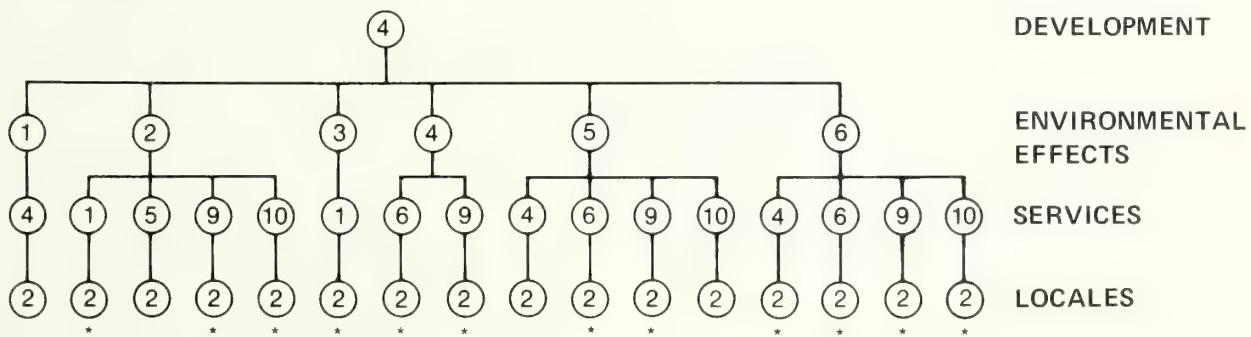
However, the developer—using the supply-response viewpoint—may ask the research question somewhat differently:

In the course of building suburban residences (locale 2, development 4), what effects will such development have on natural systems of the environment that can be enhanced, protected, or avoided through manipulation of vegetative composition, density, patterns, or productivity?

Here the package code is:

Developments (residences)	Effects	Services	Locales (suburban)
4	?	?	2

The missing parts of the package can be supplied by referring to figure 12 (residences) and tracing through the paths (or subsystem) where the two codes (4 and 2) exist. Those parts of the system are:



The number in each circle follows the number system for services, effects, developments and locales found in table 1. An asterisk along the bottom line of numbers indicates a high-priority package.

We conclude from this flow that:

1. Capabilities in all six environmental categories are required.
2. Six social services are also interrelated with residences:
 - a. Water supply and waste disposal (1)

- under two environmental effects.
- b. Housing (4) under three environmental effects.
 - c. Transportation (5) under one environmental effect.
 - d. Recreational structures (6) under three environmental effects.
 - e. Health and welfare (9) under four environmental effects.
 - f. Recreational activity (10) under three environmental effects.
3. Three-quarters of the indicated study areas have high priority.

Advantage of Using All Three Viewpoints

A research administrator, using the previous example of how the system works, has an outline to help him evaluate a research proposal or to develop a research program. The research administrator also sees that the wildlife-habitat research program described in the example about an environmental-effect viewpoint could constitute work in 20 to 25 percent of the suburban planner's environmental problems that are amenable to vegetation management. Both

the suburban developer and the policy-maker understand their roles in the total research picture.

Decision-makers from all three viewpoints now have broader based views, and they should be able to communicate their needs and problems with one another much more quickly and surely.

Thus the reinforcing feedback loop of information mentioned earlier for all three viewpoints becomes readily apparent in the total system.

RESEARCH PLANS TO ENHANCE THE SYSTEM

Recognized Weaknesses

The Pinchot Institute recognizes at least nine aspects of this first-generation system for exploratory research and problem evaluation that need improvement:

1. Components in table 1 need to be revised and expanded where necessary.
2. Problems suggested by individual packages and groups of packages need to be defined explicitly.
3. Where answers to parts of problems already exist, results should be published in concise, compact form for use by decision-makers. In this same regard, a continuous literature review is required to update and publish supplements to the initial reports.
4. Dependent and independent variables in each problem, or associated problems, need to be clarified.
5. Parallel and interconnecting links among and within the major components of the system need to be explored in preliminary pilot research studies.
6. Preliminary research studies are needed to adequately assess the need for concentrated research at given points or interconnecting sections of the system.
7. With the exception of a somewhat gross attempt to set priorities, a weighting procedure needs to be developed within the total system for allocating limited research funds and manpower.

8. As the system becomes more complex, retrieval computer procedures will need to be developed that will allow a given management problem to be defined from all three viewpoints and to print out either the location within the Consortium where the expertise exists to solve the problem or the references in the literature where the total or partial solution to the problem can be found.
9. As information about the total Pinchot Institute system becomes available, multidisciplinary teams need to model the research-allocation system for a variety of environmental problems. Such an approach should eventually provide an optimum combination of packages that could be funded according to an expected payoff matrix of results.

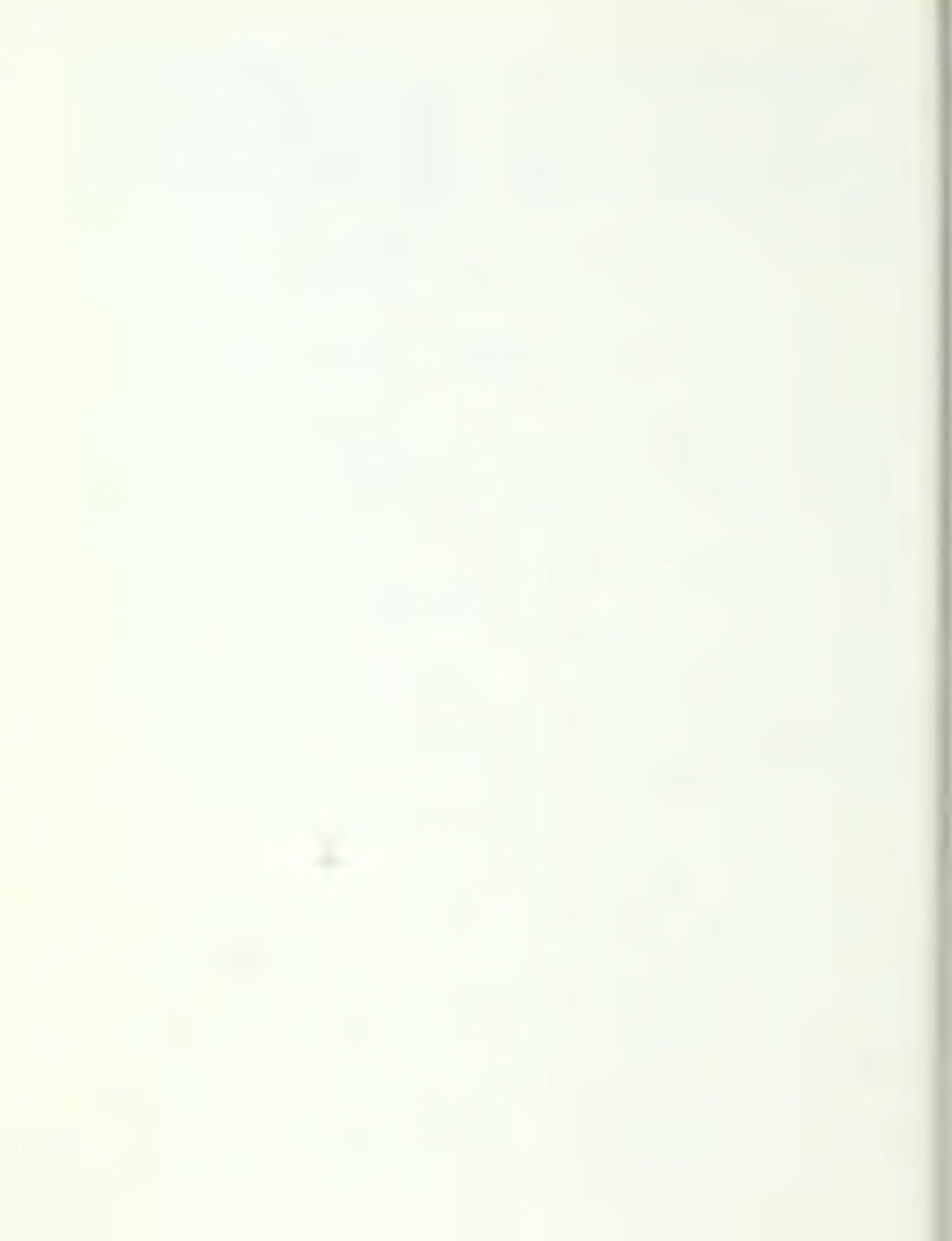
Multidisciplinary Team Approach

Multidisciplinary research teams have been established within the Pinchot Institute's Consortium of universities and inhouse research units to attack the nine basic weaknesses mentioned above. With the capability to utilize the expertise of many disciplines that exist throughout its nine leading institutions, the Institute's Consortium can create almost any type of multidisciplinary team that may be required to solve environmental forestry problems throughout Megalopolis. The Consortium has the physical plant capabilities to comprehensively and quickly engage in research to

answer the ecological-oriented problems of metropolitan planners and developers.

Starting with a given viewpoint, each team examines groups of research packages within various parts of the total system. Examples of elements to be considered by teams using each viewpoint have been listed previously in the

descriptions of those three viewpoints. When a team is satisfied that it has considered most of the important dependent and independent variables of interest, the framework for writing a problem analysis and for developing individual research studies becomes fairly straightforward.



APPENDIX I

CHARTER OF THE CONSORTIUM FOR ENVIRONMENTAL FORESTRY STUDIES

The great wave of concern about the human environment, now sweeping across the Nation, relates in part, as it has historically, to forest values in both rural and urban America.

Various public agencies and private groups are studying bits and pieces of the complex influences, interactions, and contributions of forest resources to the human environment. Many Universities and State Agricultural Experiment Stations are studying how forests and their components are affected by man's actions and, in turn, how they affect man itself. Similarly, the Forest Service, U.S. Department of Agriculture, is conducting studies in this field.

The challenge to these research agencies to find means of obtaining the optimum contribution from forest resources in and around densely-populated areas is both large and complex. And the challenge of a cohesive, coordinated research effort is too large for a single university or agency, but, through local complexity, poorly suited to a national institute. It is best attacked through a concerted effort by a regional association of agencies and institutions capable of conducting significant investigations on a coordinated basis.

The Pinchot Institute of Environmental Forestry Research, a multifunctional division of the Northeastern Forest Experiment Station, was created by the Forest Service to meet these challenges in northeastern United States. The Institute serves as a catalyst and a focal point for the scientific capabilities of a consortium of interested universities and the Forest Service brought together to solve environmental forestry-research problems of the urban-forest interface in and around the eastern Megalopolis. The Institute is the vehicle through which substantial Forest Service research grants are made to universities cooperating within the framework of the university-Forest Service Consortium.

The Consortium is organized to coordinate research activities of participating members. It will develop the knowledge and technology

needed to solve problems of policy formulation, regional planning, and land management related to environmental forestry in and around eastern population centers. It will provide for dissemination of research results in a coordinated program designed to acquaint people throughout the area with the role of forests in maintaining and improving the quality of human environment. And it will serve to attract other sources of cooperation, participation, and funds.

The Charter, which follows, will guide the operations of the Consortium.

ARTICLE I. Name and Location

The name of this consortium shall be CONSORTIUM FOR ENVIRONMENTAL FORESTRY STUDIES. The principal office shall be at the Forest Service, U.S. Department of Agriculture, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania.

ARTICLE II. Purpose

This nonprofit Consortium is formed to initiate, support, and carry out programs of research and associated graduate education relating to the urban-forest interface in the Megalopolis of the northeastern United States; to establish, maintain, and operate such facilities as may be needed to carry out these missions; to publish and otherwise disseminate the results of research; and to carry out other activities as needed in furthering these endeavors.

Research will include, but is not limited to, the following general areas:

1. Improving decision making and planning models involving social, economic, biological, and ecological analysis of forest resources in areas of constantly increasing human pressures.
2. Increasing the amenities provided by forest resources.

3. Improving the management of forested municipal watersheds for urban water supplies, recreation, and other uses.
4. Genetic improvement of intensively used forest vegetation.
5. Site requirements for landscape tending.
6. Improving wildlife habitat for spectator enjoyment, with emphasis on nongame species.
7. Improving the social wellbeing of urban people through recreation and aesthetics in a forest environment.
8. Improving the management of urban-forest ecological systems.
9. Improving the protection of high-value forest vegetation from destructive actions of man and other agents.
10. Improving urban highways and intersections with forest vegetation.
11. Improving urban man's understanding of his interrelationships with, and determining his needs for, urban forest environments.
12. Improving social institutions and arrangements for using forest resources to improve the urban environment.

ARTICLE III. Membership

The Consortium for Environmental Forestry Studies shall be composed of the Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, and selected educational institutions within the eastern Megalopolis and the territory of the Northeastern Forest Experiment Station which have programs directly related to environmental forestry. The charter educational institutions are: University of New Hampshire, Durham, New Hampshire; Massachusetts Agricultural Experiment Station, Amherst, Massachusetts; University of Connecticut, Storrs, Connecticut; Yale University, New Haven, Connecticut; State University College of Forestry, Syracuse, New York; The Cornell University Agricultural Experiment Station, Ithaca, New York; Princeton University, Princeton, New Jersey; Rutgers University, New Brunswick, New Jersey; and Pennsylvania State University, University Park, Pennsylvania. Additional educational institutions may be invited

to join the Consortium following procedures established in the bylaws.

No fee shall be required for institutional membership in the Consortium.

An institutional member may resign at any time by giving 90 days written notice to the Consortium. Forest Service membership shall continue as long as the companion Cooperative Agreement between the Forest Service and the Consortium remains in force.

ARTICLE IV. *Obligations of Member Institutions*

- A. Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, agrees to:
 1. Provide funding as permitted by Congress and appropriate budget authorities for the purpose of undertaking research described in Article II within the framework of the Pinchot Institute for Environmental Forestry Research. The Forest Service will, furthermore, undertake with its own staff and facilities, research conceived to meet the objectives of research described in Article II in the amount in value of approximately one-half of the funds allocated to the Institute for research. The other half of the funds allocated to the Institute shall be made available under separate agreements supporting research proposed by member educational institutions or by other educational institutions and which meet the objectives of the Consortium described in Article II.
 2. Furnish annually to the Executive Committee of the Consortium, as early in the fiscal year as reasonable assurance can be given, the approximate amount of funds that will be available that year for research grants that meet the objectives of the Consortium.
 3. Designate a representative to serve full time on the Executive Committee of the Consortium for continuing liaison and coordination of the entire research program of the Pinchot Institute for Environmental Forestry Research.

4. Provide logistical support in the form of secretarial and office services and supplies to the Consortium within the limits imposed by the funds and personnel administratively determined to be available for this purpose.
5. Participate fully with members of the Consortium in research problem identification and selection and research program formulation for both university and in-house research.
6. Share the cost of Consortium publications as appropriate and mutually agreed in each case.
7. Serve, participate, and contribute to all Consortium activities as mutually agreed upon by the Consortium as a whole, and to the extent permitted by Federal laws and regulations.

B. Each member Educational Institution agrees to:

1. Participate fully within the Consortium in research problem formulation for both university and Forest Service in-house research.
2. Serve and participate in all Consortium activities as mutually agreed upon by the Consortium as a whole.
3. Fund the cost of sending representatives to the annual technical and committee meetings agreed to by the Consortium. Travel policies of each institution shall control its official representative or alternate; each institution shall pay only for its own representative.
4. Publish or arrange for publishing appropriate results of the research sponsored through the Consortium and conducted by a member of the institution, according to the policies and practices of the educational institution concerned and giving due credit to the Pinchot Institute for Environmental Forestry Research for funding any grants it provides that are involved in the research reported.
5. Share the cost of general Consortium publications as appropriate and mutually agreed in each case.

ARTICLE V. *Organization*

A. *Consortium:*

Each member institution, including the Northeastern Forest Experiment Station, shall designate one official representative and one alternate representative to the Consortium. The alternate representative shall vote only in the absence of the official representative. An institution is not obliged to cause its alternate to attend any meeting unless its official representative does not attend. The alternate, however, is permitted to attend.

B. *Officers:*

The official representatives to the Consortium shall elect annually from their membership a president, a president-elect, a vice-president for research, and a secretary-treasurer. The Forest Service representative shall not be eligible to serve as an officer.

The President shall be empowered to ratify decisions of the Executive Committee by executing instruments and other papers in the name of the Consortium. Other responsibilities and authorities of the officers not otherwise described in the Charter shall be proposed by the Executive Committee and become effective when adopted by amendment to the Charter or the bylaws.

C. *Executive Committee:*

The Executive Committee of the Consortium shall consist of the above four officers plus a member of the Forest Service appointed by the Director of the Northeastern Forest Experiment Station plus a non-voting recording secretary provided by the Forest Service.

The Executive Committee shall be empowered to handle the business and affairs of the Consortium and to appoint and assign duties to such standing and ad hoc committees as may be advisable. The Executive Committee is not empowered to bind any institution to make any payment of funds or render any services to the Consortium or any third party. Actions of the Executive Committee shall be consistent with this Charter and the votes of its members. A four-fifths majority of the Executive Committee is required to initiate any action.

ARTICLE VI. *Funding*

It is expected that the principal source of funds to support research planned by the Consortium will be Federal appropriations to the Forest Service, U.S. Department of Agriculture, available for this purpose. In addition, the Consortium will accept funds from other appropriate organizations, agencies, and foundations. All proposals for funds sought in the name of the Consortium will be reviewed by the Consortium Executive Committee, which will approve or disapprove them. Member institutions may seek funds individually, without review by the Executive Committee, if such funds are not sought in the name of the Consortium.

ARTICLE VII. *Operations*

A. Internal Administration

1. *Annual Meeting.* The Consortium shall meet at least once a year at a time and place decided by the Executive Committee to discuss research program direction and progress, research funding, and other matters as appropriate.
2. *Special Meetings.* Special meetings of the Consortium will be called by the President as needed. Committees will meet as required to carry out their responsibilities.
3. *Voting.* Each member institution shall have one vote in the Consortium.
4. *Quorum.* Official or alternate representatives from two-thirds of the member institutions shall constitute a quorum for conducting the business of the Consortium. When a quorum is present, a two-thirds majority of the representatives or their alternates present and voting shall be required for initiation or approval of any action, unless otherwise specified in the Charter.

B. Research

The Consortium will:

1. Identify and select specific research problems to be pursued under the Consortium program of Environmental Forestry Studies. It may determine and set the objectives, priorities, and guidelines for studies, based on its interpretation of public need, funds available, capabilities

of institutions and persons, and other work under way within or outside the Consortium.

2. Solicit and entertain proposals for conducting the research from both member institutions and non-member institutions which desire to participate and which have the capability to contribute appropriately to the solution of the research problems selected for study.
3. Evaluate all research proposals submitted to it for which grant funds are requested and select those deemed most appropriate and feasible for contributing to solution of the research problems and priorities it has set.
4. Forward the grant proposals it has selected for Forest Service financing (within the limits of funds expected to be available) to the Director of the Northeastern Forest Experiment Station together with its recommendations, by priorities, for their financing through Forest Service research agreements. Such grants will be subject to usual Forest Service review procedures and legal restrictions.
5. Allocate non-Forest Service funds that may be available. Such funds shall be used to finance additional research proposals, or for other purposes; but the allocation shall be for the purposes intended by the contributor of the funds.
6. Review and evaluate periodically the accomplishments of the research conducted under its aegis.

C. Information Exchange

The Consortium will:

1. Arrange for printing and distributing such publications and reports as it deems appropriate. Costs will be shared equally among member institutions unless otherwise unanimously agreed, or paid from Consortium funds that may be available for this purpose.
2. Sponsor seminars, conferences, symposia, and other meetings from time to time to coordinate research in Environmental Forestry, to instruct and educate, and to disseminate results of the research. Costs of such meetings will be

shared equally among Consortium members, unless otherwise unanimously agreed, paid for from Consortium funds, or otherwise discharged as appropriate in each instance. Forest Service contribution to such costs is subject to Federal laws and regulations.

3. Seek to gain public understanding and support for the role of Environmental Forestry and Environmental Forestry Research and their influences through social and ecological relationships in attaining an improved human environment.

ARTICLE VIII.

Adoption and Amendment of Charter and Bylaws

- A. *Adoption of Charter.* The Consortium shall take effect February 1, 1971 and continue until dissolved by a majority vote of its members at the time. Institutions shall become members on the date the Charter is signed below by their authorizing official.
- B. *Charter Amendments.* Each proposed revision or amendment of this charter must be sponsored by at least three members of the

Consortium and submitted to the Executive Committee two months in advance of any Consortium meeting (annual or special) at which the proposal is to be discussed. The Executive Committee will send a copy of the proposal to each member institution at least 30 days in advance of the meeting at which discussion will be held on the proposal, together with notification of the time and place of the meeting. After discussion of the proposal at the meeting, member institutions will vote on the proposal by mail ballot. Approval by two-thirds of the member institutions will be necessary for adoption.

- C. *Bylaws.* As the need arises, Bylaws of the Consortium, and their revisions and amendments, will be developed by the Executive Committee, which will submit them to the official representatives of the member institutions in the Consortium for approval or disapproval. Such Bylaws, revisions, or amendments shall be consistent with the Charter and will become effective 30 days following the date of submission unless one-third of the Consortium members disapprove in writing before that time.

D. *Signatures.*

Institutional Member

Northeastern Forest Experiment
Station

Forest Service, USDA

Authorizing Official

by: _____
(Name)

(Title)

(Date)

University of New Hampshire
Durham, New Hampshire

by: _____
(Name)

(Title)

(Date)

Massachusetts Agriculture
Experiment Station
Amherst, Massachusetts

by: _____

(Name)

(Title)

(Date)

University of Connecticut
Storrs, Connecticut

by: _____

(Name)

(Title)

(Date)

Yale University
New Haven, Connecticut

by: _____

(Name)

(Title)

(Date)

State University College of
Forestry
Syracuse, New York

by: _____

(Name)

(Title)

(Date)

The Cornell University
Agricultural Experiment
Station
Ithaca, New York

by: _____

(Name)

(Title)

(Date)

Princeton University
Princeton, New Jersey

by: _____

(Name)

(Title)

(Date)

Rutgers University
New Brunswick, New Jersey

by: _____

(Name)

(Title)

(Date)

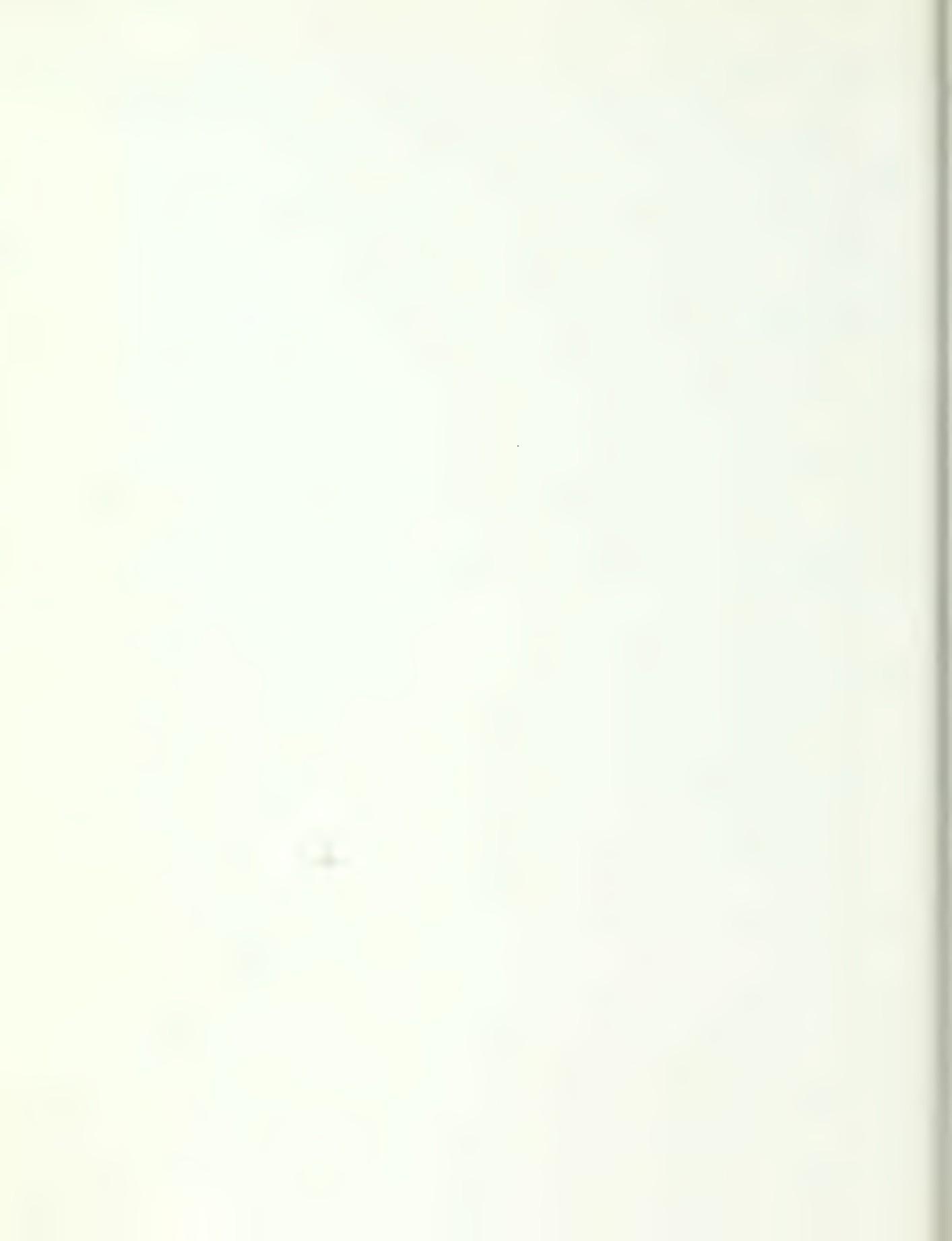
Pennsylvania State University
University Park,
Pennsylvania

by: _____

(Name)

(Title)

(Date)



APPENDIX II

DEFINITIONS OF TERMS

SERVICES

Human problems are much more complicated today than when man was a hunter-gatherer. The basic problems of survival remain, but they are overlain with a fabric of refinement that creates multiple interrelated problems. These problems are often difficult to perceive in anything approaching totality, whereas single problems were more easily brought into focus. To deal with modern complexity of human existence and focus on understandable entities, society recognizes broadly needed services. These are the vehicle for specifying human problems.

Physical infrastructure.—Those services requiring the creation of physical structures.

1. Water supply and waste disposal: the supply of water for various requirements of man and the disposal of water-borne wastes.
2. Energy: the provision of all forms of utilizable energy in required amounts.
3. Transportation: movement of people, goods, energy, and services.
4. Housing: provision for the shelter of individuals or families.
5. Flood control: the protection of human life and property from flood damage.
6. Recreational facilities: that recreation requiring development. Recreational activities described are part of the social infrastructure, and therefore are included as separate service item number 10.

Social infrastructure.—Those services required by man in his existence in the context of society. While their provision may or may not require physical structures, they are classified in the sense of providing man's social needs.

7. Education: the imparting or acquisition of knowledge, skill, or culture through instruction, training, or study.
8. Employment: the exchange of labor, either physical or mental, for value consideration.
9. Health and welfare: satisfactory conditions of physical and mental health, including

the nourishment, medical supplies and services, and economic requirements of man.

10. Recreational activities: activities for the physical and mental recreation of man.

LOCALES

Locales include any location or place where the services just described are needed or provided. In this system the locale is categorized as follows:

1. Urban: the most heavily developed portion of a city, characterized by high human density, multi-storied buildings, high density of buildings, and scarcity of open space.
2. Suburban: the outlying part of a city or town or adjacent smaller community characterized by moderate human density, single or low-numbered multifamily dwelling, lower building density, and presence of open space around buildings—usually yards.
3. Exurban: those areas around a city, usually beyond the suburbs, characterized by low human density, single-family dwellings, very low building density, and presence of large amounts of open space, often in the form of fields and forests, but not as the dominant landscape character.
4. Rural: those areas that are not part of a city, usually beyond suburbs and exurbs, characterized by low human density, single-family dwellings and outbuildings, with expanses of fields and forests as the dominant landscape character.

DEVELOPMENTS

Man applies his energies in an engineering fashion to produce constructs with which he satisfies his needs for services. We have called these developments. These developments are defined as follows:

1. Heavy industry: that industry that utilizes large amounts of energy and raw material in the more primary stages of raw material conversion, or in the production of large volumes of finished products. These industries

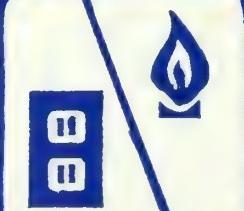
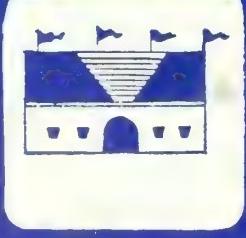
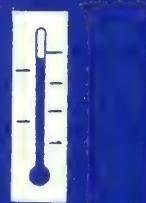
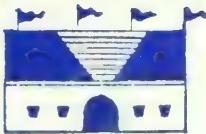
- usually cover large acreages and are potentially heavy polluters. Examples include pulp and paper mills, chemical plants, metallurgical plants, and steel plants.
2. Light industry: that industry that is usually labor-intensive and provides secondary or tertiary manufacture. These industries usually cover smaller acreages and are not high-volume polluters. Examples are wholesale and retail outlets, electronics firms, and design and consulting firms.
 3. Power: those structures that provide for the direct production (excluding extraction) or conversion of energy. Examples are power dams, power plants, oil refineries, and gas plants.
 4. Residences: includes all dwelling places for man—houses, apartments, hotels, and dormitories.
 5. Transportation system: includes the structures necessary for transportation of people, goods, and services. Examples are roads, railroads, subways, waterways, sidewalks, pipe lines, power lines, telephone and telegraph lines, and airports.
 6. Cultural and institutional structures: includes all structures concerned with development of intellectual and moral faculties by education; provision of facilities for the development or exercise of aesthetic and intellectual appreciation; provision of facilities for man's health and welfare. Examples include schools, churches, hospitals, and museums.
 7. Forestry: the husbandry and manipulation of forests. Examples include timber harvesting, timber-stand improvement, tree planting, and habitat manipulation for wildlife.
 8. Agriculture: the husbandry and manipulation of nonforested land to produce crops and/or livestock. Examples include farming, dairy farms, sheep grazing, and beef production.
 9. Mining: the extraction of minerals (nonrenewable resources) for utilization by man. Examples include oil, gas, coal, gravel, and metallic minerals.

ENVIRONMENTAL EFFECTS

In his efforts to provide needed services in appropriate locales through developments, man often causes changes in various aspects of the environment. The following are environmental effects that may result from any course of action:

1. Air quality: deals primarily with impurities added or deleted from air including gaseous, particulate, and radioactive matter.
2. Water: includes quality, which deals with the addition or deletion of impurities from water, including both organic and inorganic materials and considering temperature and quantity, which in turn deals with flow duration and amount.
3. Soil: the change of one or more soil characteristics such as through addition of effluents, alteration or disturbance by engineering works, or changes in groundwater table level.
4. Temperature and humidity: changes in ambient temperature and humidity. They are considered together because of the magnitude of interdependence. Initial trials indicated that resultant packages were almost identical when temperature and humidity were considered separately.
5. Noise: changes in amount, type, or quality of sound perceived by the human ear.
6. Flora and fauna: changes or effects on plant and/or animal communities. Fauna was combined with flora because fauna is dependent on the habitat provided by flora. Initial trials indicated that the resultant packages were almost identical when flora and fauna were considered separately.





FOREST FERTILIZATION

Symposium Proceedings



PLANNED AND PRESENTED by
the Northeastern Forest Soils Conference

SPONSORED by
the Canadian Forestry Service and
the USDA Forest Service, Northeastern
Forest Experiment Station

HOSTED by
the State University of New York College
of Environmental Science and Forestry



USDA FOREST SERVICE GENERAL TECHNICAL REPORT NE-3
1973

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

FOREWORD

FOREST FERTILIZATION is a cultural practice becoming available to forest land managers for use in meeting management objectives. Like other cultural practices, it involves an investment in the site, it may result in an array of side effects in the ecosystem, and it must fit logically into long-range management plans.

It has long been known that if nutrient elements are critically deficient on a site for particular plant species, and the rest of the physical environment properties are adequate, the addition of such elements will improve the growth and development of these plants. What has limited forest-fertilization practice in the past is economic feasibility, the interactions within the environment, and more recently the environmental impacts of this practice.

We need to know the differences in nutrient element demands by different tree species at different densities of stocking and different stages of development. We need to know the availability of nutrient elements on a site in relation to the total physical environment and biota. And we need to be able to properly diagnose which element is low or limiting for a given site and species, and how much of the element is required for optimum effectiveness. We need to know how to predict the magnitude of growth and other responses that can be expected from given treatments for different sites and species, and the values to management of these responses compared to the investments in fertilization practices.

Some of this information is known, for some regions, sites, and tree species. However, in the northeastern United States and eastern Canada, relatively little information is available, and relatively few forest-fertilization programs are in action. And within our region, it appears that the information for eastern Canada may, in some respects, surpass that information available in the northeastern United States.

There are many reasons for the apparent lack of this cultural practice in our region: the variety of land-use objectives, land-ownership patterns, markets, and current concerns of environmental quality in the megalopolis region. Though information about the use of fertilizers to increase wood-fiber production in our region is inadequate, there is even less information about fertilizer programs for non-wood production uses of land in eastern Canada and northeastern United States; for example, recreational site development. Regardless of land-use, healthy, vigorous vegetation is a general common concern. In many places, a carefully designed forest-fertilization program may be worth considering.

When the Northeastern Forest Soils Conference decided in 1970 to form a Committee on Forest Fertilization, it drew together an expression of interest in this cultural practice in the region. This regional Symposium is an outgrowth of the interest expressed.

This Symposium is presented by the Northeastern Forest Soils Conference, with support and financial backing by the USDA Forest Service and the Canadian Forestry Service, and with the cooperation of the State University of New York College of Environmental Sciences and Forestry. We hope a step ahead has been taken in organizing existing information on this subject and in expressing the potential value of this cultural practice in our region.

—ALBERT L. LEAF and RAYMOND E. LEONARD

Dr. Leaf is Chairman, Committee on Forest Fertilization, Northeast Forest Soils Conference, and Professor of Forest Soil Science and Chairman of the Forest Resources Council of the State University of New York College of Environmental Science and Forestry, Syracuse, N. Y. Dr. Leonard is Research Forester, Northeastern Forest Experiment Station, Forest Service, USDA, Durham, N. H.

FOREST FERTILIZATION

Symposium Proceedings



**THIS SYMPOSIUM
ON FOREST FERTILIZATION IN AN ENVIRONMENTAL
SETTING IN THE NORTHEASTERN UNITED STATES AND
EASTERN CANADA**

was held at the Charles Lathrop Pack
Demonstration Forest on the Warrensburg Campus
of the State University of New York College of
Environmental Science and Forestry,
22-25 August 1972.

PLANNED AND PRESENTED by
the Northeastern Forest Soils Conference

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the Canadian Forestry Service, Department of the Environment,
and the Northeastern Forest Experiment Station, USDA
Forest Service

HOSTED by
The State University of New York College of Environmental
Science and Forestry

COVER PHOTO: View of Charles Lathrop Pack Demonstration Forest, site of pioneering forest fertilization research in the United States and host to the Forest Fertilization Symposium.

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Management, Syracuse Campus,
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OPENING REMARKS

ON BEHALF OF THE U.S. FOREST SERVICE

by WARREN T. DOOLITTLE, *Director, Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Upper Darby, Pa.*

ALL OF US are deeply indebted to the sponsors of this Symposium, and particularly to the Northeastern Forest Soils Conference and the State University of New York College of Environmental Science and Forestry. I know Al Leaf worked very hard on this program on behalf of both the Conference and the College, and I am particularly pleased to have the Canadian Forestry Service join with the U. S. Forest Service, the Conference, and the College in planning, sponsoring, and carrying out this affair.

It seems especially fitting that this Symposium is being held here at Pack Forest. Pack Forest is a sort of cradle of fertilization here in the United States. It was here, some 20 years ago, that Sven Heiberg and Don White were finding out that severe deficiencies in certain nutrient elements drastically reduced the growth and development of red pine and other species. Of particular concern was potassium, which was a major limiting factor on abandoned farm lands that had been planted to trees.

Since then, much other fertilizer and nutrient research has been conducted here and in other places across the continent. Much has been learned about nutrient deficiencies and the interrelationship of nutrients, plants, soil, and water.

More recently, researchers have begun

to look at some of the side effects of fertilizers and nutrients as they relate to level of application and forest treatment or management—particularly timber removal and fertilization. We will hear more about these side effects later in the program.

Though most of us are probably interested primarily in fertilization as a means of increasing tree growth and wood production, I am glad to see that we are also going to be looking at the positive and negative values as fertilization relates to special forest crops, recreation, wildlife habitat, water production, revegetation of disturbed land areas, and insect and disease control.

As you know, critics of forestry today are very quick to use our own research against us, especially where negative values from certain practices have been reported. A good example has been the results of nutrient cycle studies at the Hubbard Brook Experimental Forest in New Hampshire. The loss of nutrients from a cutover and chemically treated watershed was repeatedly picked up and reported as what happens after clearcutting of New England hardwood stands. Furthermore, these results were projected nationwide to show the effects of clearcutting.

More recent studies at Hubbard Brook have shown results of nutrient losses fol-

lowing conventional timber cutting methods. While the loss of nutrients is still higher than we would like to see, we now have something more realistic to work with, and prompt regeneration promises to further minimize these losses.

I cite this example of a side effect for two reasons. First of all, we need to know what is happening when we cut, fertilize, or otherwise treat our forest stands. Such knowledge may cause us to change or correct certain management techniques. In harvesting timber on certain soils or in revegetation efforts following fire or surface mining, we may find it necessary and desirable to add fertilizer to replace or renew certain nutrients.

And second, we need to be alert to the implications of some of our research. By this I mean that we need to report our results in such a way that they will be interpreted correctly. This means using proper terms and labels; it also means

discussing the results fully and not allowing partial or leading implications that may contribute to erroneous conclusions by others.

Much research has been accomplished on the use of fertilizers and the basics of nutrient deficiencies. Much still needs to be done in relating fertilizer levels to specific species, soils, and management objectives. Much of the job remaining is a job for research, but an important part of the task involves the classification and relation of tree performance to soils and nutrient levels. We also need to know the many possible side effects of fertilizers for these soils and trees. In fact, the number of combinations of possible treatments, species, soils, and side effects is frightening; this task will surely require a careful setting of priorities and selection of tasks. Gentlemen, you have your work cut out for you.

ON BEHALF OF THE CANADIAN FORESTRY SERVICE

by PETER J. RENNIE, *Program Coordinator, Soils, Program Coordination Branch, Canadian Forestry Service, Department of the Environment, Ottawa.*

IT IS UNFORTUNATE these days that the predominant may never be as newsworthy as the trivial. The normal is displaced by the bizarre. And the solid achievements resulting from regular, informal, and matter-of-fact exchanges tend to be forgotten. This is nowhere truer than in United States-Canadian relations, and in forestry it might almost be regarded as strange to examine the countless exchanges between our two countries or to begin to quantify the value of such exchanges.

Nevertheless, I believe it is sometimes necessary to remind ourselves of the intimacy of our relationships, and they have nowhere been more genuine than in the meetings of the Northeastern Forest Soils Conference. Informal and enjoyable scientific excursions have been held for many years in both our countries in the Northeast. These have done much to develop personal friendships and to foster a mutual awareness and understanding of one another's problems in forestry and soil science.

When I first heard of the proposal to mount a formal regional symposium whose theme was to give emphasis to forest fertilization in an environmental context, I was confident that the solid base of contacts built up over the years would contribute much to such a symposium's success.

But there were other reasons why we in Canada should wish to support this Symposium and why the Canadian Forestry Service of the Federal Department of the Environment responded immedi-

ately and positively to the invitation to join in co-sponsorship. Interest in forest fertilization in Canada has escalated rapidly within the past few years. As elsewhere, programs as yet are largely research and development, rather than operational; but numerous different agencies are active. There is industry itself; there has been industry in collaboration with the Pulp and Paper Research Institute of Canada; there are the forest services of certain of the provincial governments; there are the universities; and there is the Federal Canadian Forestry Service.

I do not wish to bore you with statistics, but collectively these agencies are devoting over 30 professional man-years and one million dollars annually to forest fertilization and closely related mineral nutrition. Moreover, programs range from over 250 field trials to numerous complementary studies covering adult forest, nursery nutrition, and special situations such as fertilization to secure dominance in overdense stands, to improve Christmas trees, and so forth.

Finally, those of us who have approached forest fertilization from the traditional nutrition side have for some time been slotting our studies into a somewhat wider context, where the nature of the reactions of our fertilizer materials with the inanimate and vital components of the ecosystem have been receiving attention for the purpose of increasing the efficiency of fertilization. The logical extension of this development is concern for even wider environmental issues. To

give you an example, the Canadian Forestry Service is now one element of a much more comprehensive federal department in which the interests of water management, environmental protection, fisheries, wildlife, and land inventory find greater scope for collaborative endeavour. It is not surprising, therefore, that several joint studies have commenced in which the environmental impact of forest-management practices, including of course fertilization, is the center of focus. In fact, the days of seeking a mere growth-response are over: we seek a reliable, economic, and environmentally safe technology.

Because these aspirations are very much those of the United States Forest Service, it is most apposite that we should join forces to sponsor this novel Symposium, for I am not aware of the nutritional and environmental themes being previously fused to form the basis of a forest-fertilization meeting. Knowing the content of the formal contributions that are about to be presented, I have every belief that our Symposium is in the van of progress and will serve as the forerunner of others similarly conceived.

I am sure that all Canadians from all agencies formally contributing and participating in our Symposium will appreciate the co-sponsorship of the United States Forest Service, expressed through

Dr. Warren T. Doolittle, director of the Northeastern Forest Experiment Station, which has made this Symposium possible. We are privileged to enjoy the hospitality and pleasant surroundings of the Charles Lathrop Pack Forest, thanks to Dr. E. E. Palmer, president of the State University of New York College of Environmental Science and Forestry.

Again, I think it is appropriate that Americans and Canadians should be meeting in this historic Hudson-Champlain Valley, which over the years has been a lifeline of such significance in the development of contacts and relationships between our two countries. I notice, of course, that we are a stone's-throw from Saratoga National Park, but anticipate that the cut-and-thrust of two centuries ago will be echoed merely in the quality of our discussion sessions.

Finally, a special word of appreciation must go to Professor A. L. Leaf, as chairman of the Forest Fertilization Committee of the Conference, for successfully doing those many organizational tasks to ensure the success of our meeting.

In closing, may I say that we Canadians are aware how the pioneering work on potassium nutrition here in the Pack Forest two decades ago sparked interest, effort, and progress far outside its original context. I am sure this Symposium will constitute a similar catalyst.

ON BEHALF OF THE STATE UNIVERSITY OF NEW YORK COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY

by CHARLES C. LARSON, *Professor and Dean, School of Environmental and Resource Management, State University of New York College of Environmental Science and Forestry, Syracuse, N. Y.*

THE STATE UNIVERSITY College of Environmental Science and Forestry is honored to serve as host to this Symposium on Forest Fertilization. I take this opportunity to express our appreciation to the Northeastern Forest Soils Conference and to the co-sponsoring organizations—the Canadian Forestry Service and the U. S. Forest Service—for having given us the opportunity to serve in this capacity.

It is a privilege and great pleasure, indeed, to welcome you in behalf of the College to our Warrensburg Campus, perhaps better known to most of you as the Charles Lathrop Pack Demonstration Forest. Established in 1927 through the generosity of the late Charles Lathrop Pack, this campus embraces an area of some 2,400 acres. It is one of five field campuses that the College operates in support of its instructional, research, and public service programs.

The other four field campuses are located at Newcomb, Wanakena, Cranberry Lake, and Tully, New York. The *Newcomb Campus* is the site of the Archer and Anna Huntington Wildlife Forest and the Adirondack Ecological Center. The *Wanakena Campus* is the home of the Ranger School Forest Technician Program, which is being upgraded to a 2-year associate of applied science degree program beginning this year. The *Cranberry Lake Campus* includes another Charles Lathrop Pack Demonstration

Forest and the Cranberry Lake Biological Station. The *Tully Campus*, situated south of Syracuse, consists of the Svend Olaf Heiberg Memorial Forest and a Genetic Field Station.

The Campus at Warrensburg serves as the permanent site of the College's summer session in field forestry. This is a 5-week, 6-semester-hour program, emphasizing the field application of forestry principles. It is offered to students in the resource management and forest biology curriculums.

Apart from serving as a major base for field instruction in forestry, the Pack Forest has been for many years the center of much of our field research effort in forestry. Research currently under way on the property involves both College-based and Forest-based projects. Included among the former are investigations in forest soils, fertilization, solar-energy relations with vegetative cover types, tree improvement, the effects of air pollution on the growth of white pine, and pathology studies involving a variety of tree species.

Among the Forest-based research projects currently in progress are long-term studies of white pine growth, the relation of white-pine weevil damage to red heart rot in white pine, lumber grade recovery in white pine and hemlock, high pruning in white pine, the development of specialty uses for low-grade timber products, new techniques in the stabilization of

wood products, and the conversion of bark to humus by composting.

The Forest continues, as always, to serve as a demonstration of white pine silviculture and as a major attraction for students, professionals, and others interested in the management of this species.

Forest fertilization research conducted by our College to date has been centered largely at Warrensburg. Following acquisition of the property in 1927, there was a 5-year period of active tree planting on the abandoned agricultural lands of the area. For the most part, these lands had deep sandy soils of low productivity.

About 5 or 6 years after planting, the trees on these areas, mostly red pine, exhibited a significant reduction in growth rate. In an effort to correct this situation, the late Svend Heiberg, then professor of silviculture at the College, initiated a series of trial applications of organic matter, followed by addition of fertilizer salts.

The first application of commercial fertilizers in Pack Forest plantations was made in the spring of 1937, which may be taken as marking the beginning of forest fertilization research at this institution. Since that time the research efforts by faculty and graduate students have documented the particular nutrient element deficiencies, including potash deficiency, and the rate of fertilizer application for near-maximum response in coniferous tree growth on these depleted sandy soils.

During the last decade, research has emphasized developing a better understanding of the physiological-ecological bases of the growth response, of the role of fertilizers in the forest ecosystem, of the effects of stand manipulation, and of the relation of fertilizers to the total physical environment.

From its initiation through 1964, the research in forest fertilization was carried on under the leadership of Professor Heiberg. Since then, Dr. Albert Leaf has

provided immediate direction of the research in this sphere.

Support for our forest-fertilization research has derived from both State and outside sources. During the decade of 1959-69, over \$100,000 was contributed to the program by the National Science Foundation. Significant contributions to the research have also been made by the U. S. Forest Service.

Our College, like professional forestry organizations everywhere, has been striving for some time to adjust its overall program of instruction, research, and public service to better accommodate the growing concerns of our society for forest-based goods and services and for environmental quality in general.

At the heart of such adjustment, of course, is change—change in programs, in priorities, in organization structure. The process of effecting change in academia is at best an exceedingly slow and difficult task. To accomplish it with reasonable dispatch and success during a period of rapidly expanding academic workloads and declining budgets is well nigh impossible, and certainly a challenge.

Established as a State-supported institution at Syracuse in 1911, the College has enjoyed the advantages, and suffered some of the disadvantages, of developing its program independently of a college of agriculture, the traditional mother institution for professional forestry education in America. Blessed with broadly-conceived enabling legislation, its own governing board of trustees and a wide degree of independence, the College from its very beginning developed a comprehensive approach to professional forestry and, accordingly, a diverse program of instruction, research, and public service.

To better reflect the broad scope of its programs and competence in relation to forest land resources and their associated environments, the name of the College was recently changed by legislative action to "State University of New York

College of Environmental Science and Forestry."

The inclusion of "Environmental Science" in the new name was to emphasize, better than does the term "Forestry" alone for most people, the fact that this College is qualified by virtue of program, mission, and capability to contribute in a major way toward helping to solve many of the environmental problems of our day.

In conjunction with the name change, the enabling legislation for the College was revised to reflect this environmental capability, as well as to incorporate other changes that have occurred in New York State's educational system since the original legislation for the College was adopted.

The College is presided over by a President (Dr. Edward E. Palmer), assisted by four Vice Presidents representing Academic Affairs, Research, Student Affairs, and Administration. Its current organizational structure embraces, in addition to the five field campuses previously mentioned, four academic schools and three research institutes: The School of Biol-

ogy, Chemistry and Ecology; the School of Environmental and Resource Engineering; the School of Environmental and Resource Management; the School of Landscape Architecture; the Applied Forestry Research Institute; the Empire State Paper Research Institute; and the State University Polymer Research Center.

In addition to the three research institutes, the U. S. Forest Service maintains at the College a Cooperative Research Unit that serves to supplement and further strengthen our overall research capability.

The School of Environmental and Resource Management, over which I have the privilege of presiding at present, has responsibility for the professional forestry curriculum of the College. This School has been undergoing rather substantial change during the past year.

I extend to each of you a hearty welcome on behalf of the administration, faculty, and students of the State University of New York College of Environmental Science and Forestry. We wish you a most pleasant and productive conference.

ON BEHALF OF THE NORTHEAST FOREST SOILS CONFERENCE

by WALTER H. LYFORD, *Secretary-Historian of NEFSC and
Soil Scientist, Harvard Forest, Harvard
University, Petersham, Mass.*

THE NORTHEAST FOREST Soils Conference (NEFSC), through its Committee on Forest Fertilization, is privileged to present this Forest Fertilization Symposium.

The NEFSC started at the Harvard Forest in 1939 with a meeting of a few foresters and soil scientists interested primarily in forest soils, their classification and mapping, productivity and management. Except for a few years during World War II, yearly field-trip meetings have been held in the summer. In the early 1950's, Canadians joined the group, and since then the meetings have been held both in eastern Canada and northeastern United States; for example, in 1971 we met in New Brunswick, in 1972 in West Virginia.

This group is really not an organization. It has a mailing list of about 200 individuals, but there are no membership dues, bylaws, or officers (except for a permanent secretary-historian whose duty is to act as a repository for the records). The chairman of each year's 1 ½- to 2-day field-trip meeting is a forest soil man in the host state or province, and he arranges the field trip for that year. As soon as the field trip is over, he sends the mailing list and any extra

funds or debts to the man who will run the field trip the next year.

On these field trips several sites are visited, and the soil and forest on these sites are examined and discussed in detail. Generally 60 to 80 commercial foresters, university faculty, extension foresters, and employees of state or province forestry organizations, Canadian Forestry Service, U. S. Forest Service, and Soil Conservation Service attend.

Generally one or two informal committees are formed each year to examine and report on some matters of current interest. These committees are autonomous and no attempt is made to achieve long-term goals or end up with published reports. However in the past decade publications have resulted from committee work. For example, the Site Classification Committee (E. L. Stone, chairman) in 1961 produced *PLANTING SITES IN THE NORTHEAST*, published by the Northeastern Forestry Experimental Station, Upper Darby, Pa. and the Forest Nursery Soil Improvement Committee (R. A. Farrington, chairman) in 1965 produced *PROCEEDINGS OF NURSERY SOIL IMPROVEMENT SESSIONS*, published by the State University College of Forestry at Syracuse University, Syracuse, N. Y.

MODERATOR'S STATEMENT

by EDWIN H. WHITE, *Symposium Moderator and Assistant Professor, Department of Forestry, University of Kentucky, Lexington, Ky.*

FOREST fertilization is fast coming of age as a silvicultural tool in many parts of North America. This is evidenced by the increasing intensity of both research activities and economical field applications of fertilizers to correct known nutrient-limiting tree growth in forest stands. The major responses of southern pines to phosphorus applications on the poorly-drained flatwood soils of the southeastern Coastal Plain and the nitrogen responses demonstrated in the Pacific Northwest are excellent examples of commercial applications of fertilizers to forest stands.

Several industrial-university cooperative research programs have been established to elucidate both the basic and applied problems associated with forest fertilization. Notable among these are the Cooperative Research In Forest Fertilization program (CRIFF) at the University of Florida and the North Carolina State University Forest Fertilization Cooperative.

Several meetings, beginning with the Duke University symposium on mineral nutrition of trees in 1958, and including the TVA Symposium on *Forest Fertilization . . . Theory and Practice* in 1967 and the Third North American Forest Soils Conference in 1968, focused major attention on tree growth and mineral nutrition. However, even as the demand for wood products from the forest is increasing, so also is there pressure to preserve or improve the quality of the environment. Applications of fertilizers to forest stands affect much more than wood production, including the water, wildlife, and recreation aspects of a forest ecosystem. In eastern North America the most important forest resource in the near future may well be quality water.

The papers of this Forest Fertilization Symposium reflect the growing awareness by forest researchers of the total ecosystem approach to forest-fertilization problems and potentials in eastern North America.

REGIONAL OBJECTIVES IN FOREST FERTILIZATION: CURRENT AND POTENTIAL

by EARL L. STONE, *Charles Lathrop Pack Professor of Forest Soils, Department of Agronomy, Cornell University, Ithaca, N. Y.*

ABSTRACT. A region defined by a 1,500-km. diameter (465-mile radius) circle around Warrensburg, N. Y., contains a variety of climates, vegetation types, and economies. With but a small fraction of the land area, this region contains between one-fourth and one-third of the total population of North America north of Mexico. The vast and varied impacts of this great population impose an increasing degree of regional concern with uses and values of forest land. Nine regional objectives for use of this land are discussed.

I TAKE IT that my task today is to state our interests in holding this conference, and to remind ourselves of various facts and hypotheses that make up the background for our discussions. The following speakers may build upon this groundwork or, on the other hand, may amend, reshape, or destroy it.

My assigned title somehow implies that we are dealing with a defined geographic region and, moreover, that the objectives appropriate to it are in some way unique or different from those applicable to other regions. At first glance, neither of these assumptions seemed self-evident to me. To begin with, probably no two of us would draw the same geographic or ecological boundaries around our region. And I suspect that every other region would claim some substantial interest in each of the objectives we shall list.

OUR REGION

But to focus our attention and to free us from the tyranny of existing boundaries I have arbitrarily created a circular region, 1500 km. in diameter, and centered on our meeting site here at Pack Forest (fig. 1). The borders of this region are wholly free of bias, though perhaps inconvenient at points and likely to be distressing to administrators who properly must think in terms of states, provinces, and counties. But any one who wishes to modify the borders is welcome to replace some of the inordinately large area of ocean with presently excluded portions of New Brunswick, Ontario, or West Virginia or to exchange Virginia pine for more black spruce or balsam.

Our idealized region is some 465 miles in radius—a day's drive wherever roads permit. And so the first characteristic of



Figure 1.—The circle delimits an idealized region of 1,500-km. diameter, centered on the Pack Demonstration Forest near Warrensburg, New York.

our region is proximity, and an opportunity, whether or not we exercise it, for first-hand acquaintance with the entire range of ecological and economic conditions that we will discuss in these 3 days.

The second obvious characteristic of our region is population density and, perhaps less obviously, its distribution. No matter how we modify the boundaries of the region, it will contain more than 60 million people, somewhere between a quarter and a third of the total population of North America north of Mexico. And this number is not entirely concentrated between Boston and Richmond. Only the absence of roads in the north isolates any part of the region by more than a day's car travel for some millions of people.

I have no intention of reciting projections about further increases in this pop-

ulation or its consuming habits, mobility, and use of leisure time in the future. Or again, about its adjustments to shortages of water and energy or excesses of traffic and pollution. But it is certain that this population's demands for wood products, water, and outdoor recreation will continue to expand. It is certain also that few parts of the region are sufficiently remote to escape drastic increases in the value of forest land and much greater demands upon its various goods and services.

For example, I find that New York has 1.5 million licensed hunters and fishermen, one for every 20 acres of the State, including downtown Manhattan. Scarce wonder that some overflow into adjacent states and provinces. And, though population demands for wood products (*Slinn 1972*) will continue to be served in large part by imports from other regions, rising world demands will eventually, perhaps soon, make timber resources within the region relatively more valuable than they are today. I leave the details of this vision to your favorite soothsayer or economist. But regardless of what assumptions and projections we may make, the varied impacts of this population are so vast and so far-reaching they are imposing a kind of unity on the surrounding region.

So proximity to the pressures of great urban centers creates this region if nothing else does. Otherwise the forester, ecologist, or climatologist might easily object to its extent and limits (*Lull 1968*). For example, there are large variations in length and warmth of the growing season, as well as in depth and duration of snow cover. These, of course, affect the distribution of plant and animal species, forest growth rates, transportation, and certainly the scope of outdoor recreation. In many years the water-skiing season of southern Pennsylvania will overlap the snowmobiling season of central Quebec.

And though the botanical ranges of

some tree species extend widely, it is true that no species is economically significant across the entire region. An overall view of broad forest types, however, shows no convenient lines for subdivision. The center of the region is dominated by birch-beech-maple types, defined broadly as these species together with admixtures of other hardwoods, white pine, and hemlock or spruce. These both penetrate and intergrade with the oak and oak-hardwood types of the South and the great spruce-fir forests of the North. Within each of these three groups, there are pine types of economic significance.

The economic significance of the timber industries is very large in the northern third of the region, intermediate in the south, and least in an east-west central band where the impacts of settlement on present land use have been most concentrated. Nevertheless, even New York State, with its large urban centers, abandoned farmlands, and Forest Preserves, has 47 percent of its area classified as commercial forest land. As we well know, much of the region's forest, except in the mountains and the north, owes its present character to its settlement history, including agricultural clearing and abandonment, plus one to three centuries of forest exploitation and, too often, fire. Thus relatively young or cut-over forests are abundant throughout the southern three-fourths of the region, and commonly land ownership is fragmented and ownership objectives diffused. There are also many vexing questions about the extent to which the original cover of present forest has been altered, and the degree to which inherent fertility and moisture retention of soils may have suffered from these impacts. All these features concern us when we consider forest fertilization.

But plainly, province and state boundaries provide no useful division of present forest conditions, or future needs. Nor does any state or province by itself contain sufficient expertise to examine the

potential values of forest fertilization in meeting these needs.

OUR OBJECTIVES

Given such a region, what are appropriate objectives or interests of forest fertilization? Before listing these we might emphasize an almost self-evident principle, less for ourselves than for non-foresters who may read the proceedings of this conference: fertilization is merely one additional tool for manipulating vegetation. Sometimes, as on the depleted outwash sands here at Pack Forest, the results may be overwhelming. Its general use, however, will require adequate diagnoses of the limiting element or elements, and the likelihood of economic response. Commonly fertilization will be combined with other treatments that regulate plant density and select the species, genotypes, or individuals to benefit. Neither the materials nor application are cheap, so indiscriminate use over large areas is not a serious possibility except, perhaps, in occasional overenthusiastic shotgun trials.

Thus forest fertilization is best viewed as an important addition to the new and traditional tools of the silviculturalist—tools such as regeneration techniques, stand-density regulation, mechanized site preparation, fire, herbicides, drainage, and genetic improvement. Though such tools may be applied one at a time, the aim is to combine them in production systems, and the real measure of their value is their effect in combination. In addition, of course, fertilization has a place in re-vegetating exposed soils.

Our objectives overlap those of a regional silviculture, broadly conceived. I have listed nine objectives, though some are not mutually exclusive and others might easily be divided. Nor does the order of listing imply any priority:

1. Production of more and more useful wood.
2. Greater opportunities for rapid estab-

- lishment of young forest, intensified culture, and wider choice of species.
3. Repair, protection, and enhancement of vegetative cover, as on exposed soil, burned or degraded sites, and heavily used areas.
 4. Improved food and cover for wildlife.
 5. Production of specialty crops such as Christmas trees and maple products.
 6. Increased understanding of the opportunities and limitations of forest sites and species.
 7. Knowledge of the fate of applied fertilizers, and the methodology and control to insure against undesirable off-site effects.
 8. More efficient methods for assessing likelihood of response, for classifying potential productivity, and for the conduct of routine fertilization trials.
 9. Better regional collaboration among the many organizations and individuals concerned with forest fertilization.

Objectives 1 to 5 include the major interests in forest fertilization as a realistic management tool. I fear it is easy to either over-rate or under-rate its potential in particular instances, and that we shall need some patience with both before we determine satisfactory prescriptions for use.

In the past, foresters have been quite aware of differences in the economic yields of forest land, and of the association of yield with physiography, forest type, and stand condition. Moreover, they have been comfortable with a fairly sophisticated concept of site quality as the integrated result of all effective environmental variables acting over a long period of time. I think it is true, however, that they have given relatively little attention to either the action of specific limiting factors or the interaction between environmental factors and genotype except in planted forests. Nor have they had reason to do so.

In contrast, forest fertilization is based on the assumption that growth rate or

quality is limited by very specific factors — plant-available nutrients that can be positively identified and then added to the site in straightforward fashion. The effect should be increased yields of some particular product—timber, Christmas trees, wildlife food, or soil cover. This expectation derives from the emphasis on fertilizer use in agriculture, coupled with numerous reports of fertilizer response by native tree species.

But the conditions of growth in well-stocked natural forests differ in many respects from those in fields or orchards. First, the native species and genotypes we deal with have been selected, not for responsiveness to man's culture, but by evolutionary pressures acting through their capacity to reproduce, to endure and compete. Usually forests are overfull; a tree crown expands at the expense of its neighbors; and the mere presence of a species or genotype of some age is evidence of ability to compete successfully within prevailing local conditions—including the chemical environment.

Second, some large fractions of the nutrients absorbed each year are returned to the soil for eventual re-use. In some northern forests, however, perhaps over a larger area than we now appreciate, nitrogen may be shunted to long-term storage in organic residues. And third, only a fraction of the total wood produced is harvested from untended stands or those cut at long intervals. The remainder is lost by competition among overabundant stems, by other sources of mortality and cull, and in unwanted species or sizes.

Thus the opportunities to increase growth by nutrient additions, to measure such increases precisely, and then to translate increases and costs into terms of economic choice will often be quite a different matter than in agriculture. There the large gains attributed to fertilizer use actually result from the interactions of nutrient supply with other technological inputs, beginning with genotypes selected for responsiveness,

control of plant density, and careful site preparation.

The conditions of fertilizer use in agriculture are approached most closely, of course, in forest plantations. But plantation establishment is a science of its own, requiring more comment than we can give it here. We note only that the new awareness of the fertility requirements of many desirable species, joined with techniques of herbicide use, intensive site preparation, and fertilization, offers a broad new range of possibilities for establishing new stands. We can consider planting species and sites that formerly were difficult or impossible; now they are only costly. Thus we have new options for production of specialty crops, for some special purposes such as vegetation for recreation or soil stabilization, and perhaps for timber. And surely the experience here in combining fertilization with other physical inputs will in some degree influence the approach to natural regeneration and tending of young stands.

Objective 6 is basic to the rest. I do not know the exact number of native tree species within our regional boundaries, but without looking too hard at the southward margins I count some 35 to 40 of widespread commercial importance. We could find about half this number within a several-mile radius of our meeting site. Some related species are similar in wood properties but not necessarily in ecology. And to this number we might add a few others with paramount scenic or wildlife values.

Now, plainly, it is not feasible to begin studying the fertility responses of some 30 to 50 species, from seedlings to maturity. We must either concentrate on a few, or find means of generalizing, or both. We have accumulated considerable knowledge about the characteristics of these species and their adaptations to such things as climate, soil, fire, and pests. But we have relatively little exact information about their nutrient require-

ments or the degree to which growth rates and competition among species are regulated by nutrient supply.

Approached in this way, forest fertilization is a powerful technique for experimental ecology—or silvics, if you prefer. It is one of the few ways that an investigator can intervene in a large forest ecosystem without large expense or massive disturbance. With skill and good fortune he can observe growth behavior over a range of soil fertility levels without greatly altering other soil or climatic factors. It is also a means of assessing soil potential, inasmuch as marked positive responses demonstrate that neither local climate nor soil physical variables are the immediate constraints on growth. On the other hand, negative responses are sometimes equivocal and too often are buried without critical evaluation.

SOME EXAMPLES

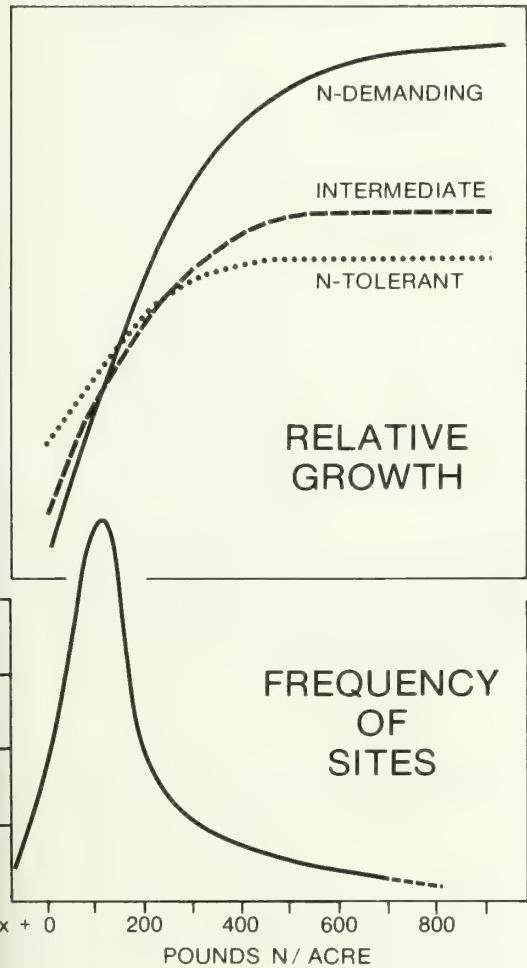
I think we have not given sufficient attention to the silvicultural implications of our limited fertilization studies thus far, and the ways these might be augmented. Let me illustrate with a group of examples, from hardwood forest, on sites that have had various degrees of disturbance.

Some 30 years ago Mitchell and Chandler (1939) examined the response of several hardwood species to added N. Among other things, they determined how the N content of foliage increased with treatment level, and so created a scale relating foliar concentration to the total supply available from soil and fertilizer. They then generalized their results by grouping species into three classes according to their relative response to increasing supply (fig. 2). N-tolerant species such as red and white oak, red maple, and aspen grew poorly at the lowest levels and responded markedly as supply increased, up to a point. But their capacity for response to high levels of N supply was limited in contrast with the

Figure 2.—Above: generalized nitrogen response curves of hardwood species. $X + 0$ indicates the available nitrogen-supplying capacity of an untreated plot bearing trees with the lowest foliar nitrogen concentration.

Below: frequency distribution of 47 unfertilized hardwood stands assessed by the foliar content of red oak.

Both figures are from Mitchell and Chandler (1939). See also Mitchell (1972).



N-demanding species—white ash, basswood, and tulip poplar. Other things being equal, N-tolerant species were superior competitors on low-N sites, and N-demanding on those with abundant available N.

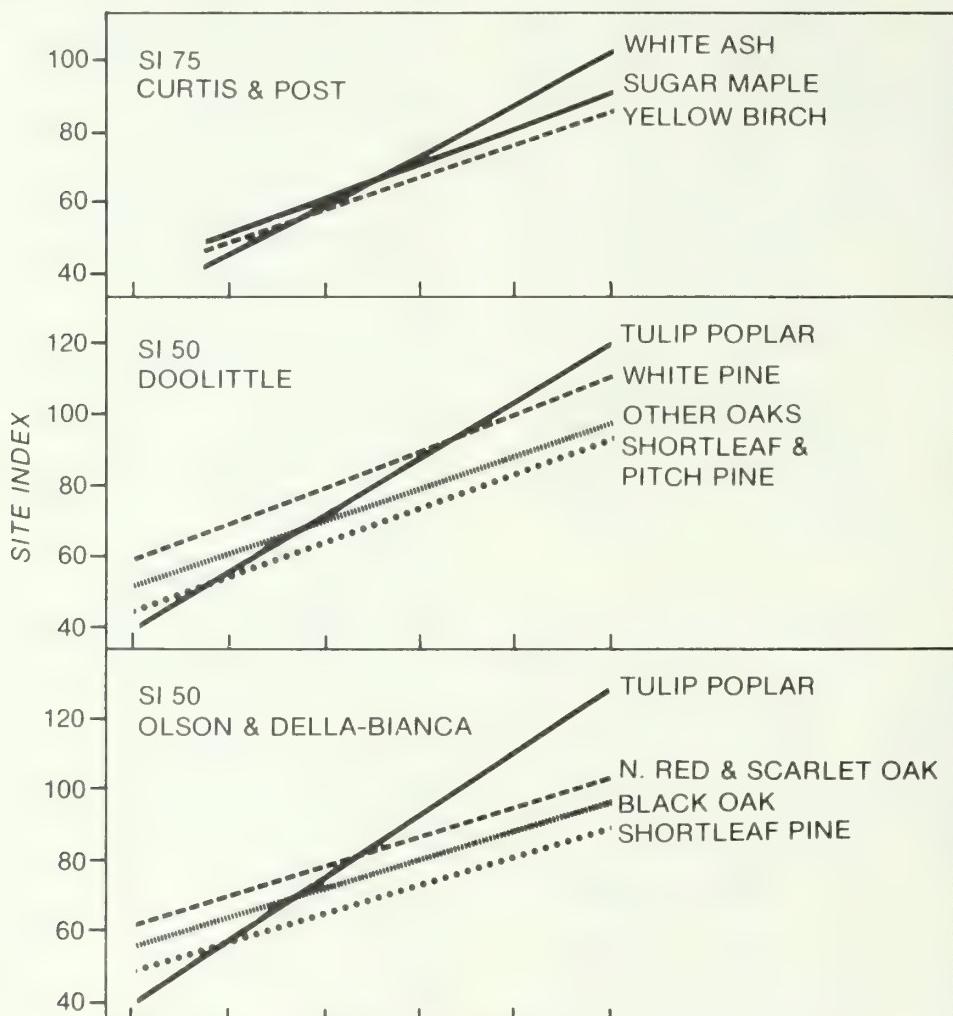
These patterns accord with common

observation. But they also agree in rather striking fashion with results from three comparisons of species growing in mixture over a wide range of site qualities (fig. 3). In none of these was N status considered. The results showed that the different growth rates of individual species on any one site tend to continue in roughly parallel fashion over the entire range of site qualities sampled. Note, however, that the sampling requirements probably excluded excessively dry, wet, and infertile sites. But white ash and tulip poplar—the N-demanding species studied by Mitchell and Chandler—are exceptions. They grow much less well than their N-intermediate or N-tolerant associates on the poorest sites, and they respond more vigorously to improved site quality.

But how commonly can we expect to find native hardwood stands on low-N sites? Regretfully, we must again turn back to Mitchell and Chandler, a third of a century ago, for any attempt at a survey within this region. Using their foliar-analysis technique to characterize available-N status, they sampled 36 unfertilized sites on which red oak was present, chiefly within a 200-mile semi-circle of our meeting site. The sample was small and certainly non-random, but the results are instructive (fig. 2). Only a small number of sites provided sufficient N for optimal growth of red oak, and fewer for the N-demanding species.

We may take the results of these several figures as suggestive rather than definitive of widespread regional conditions. But two points stand out: First, that species are far from uniform; they differ greatly in capacity to respond to improved site quality. Second, that available soil N may be a major determinant of site quality in many native upland hardwood stands, and requires at least the same consideration that we have long given to soil physical properties. Though both points require a better foundation, both plainly bear on the management of

Figure 3.—Comparative site indices of species growing together. The abscissa is dimensionless. Redrawn from studies by Curtis and Post (1962), Doolittle (1956), and Olson and Della-Bianca (1959).



sites and species, whether or not fertilization is employed.

Objective 8 takes on significance when we examine the experimental details of existing fertilization trials. These represent an astonishing variety of initial premises, experimental designs, plot sizes, replication, season of application, methods of measurements, and treatment of raw data. If soil or foliar analyses were obtained, they were obtained by any of several sampling and analytical procedures.

We understand the reasons for this diversity. It was sometimes useful and in any case inevitable in the past. But what of the future? I believe that agriculture's experience with soil-fertility research has several lessons for us.

First, there is no substitute for field experimentation. The shrewdest technical judgments and the most realistic models can do no more than extend the results obtained by experiment.

Second, it is a never-ending process, or at least as continuous as the changing

technology. At this moment we need more precise results, with more treatments and species, and for longer times, at many more locations. But it is certain that in the near future we will wish to test new fertilizers with additional species or genotypes, and especially in combination with other silvicultural treatments.

Third, field testing is costly. My colleagues' field experiments with corn in easily accessible locations throughout New York have averaged about \$100 per single small plot for labor, materials, equipment rental, travel, and computer time, quite apart from the scientist's salary. Multiply this value by suitable numbers of rates, varieties, spacings, replicates, and locations for the costs of 1 year's data for one crop, still to be summarized and interpreted.

Our own N-fertilization study in second-growth hardwoods averaged 13 man-hours field time per single 1/10- to 1/4-acre plot, for location, installation, and treatment, apart from travel and office computation. This is a measure of first cost. Now we are making our first remeasurements and discovering the limitations of our initial perceptions and design. Every investigator could relate similar tales.

But case histories are not widely useful guides for the future. Our regional interests are how—and how rapidly—we can evaluate our collective experimental successes and failures—together with those from other regions—and so derive generally applicable designs and measurement procedures that will yield more and better information for the very considerable sums that we are now investing in forest-fertilization research.

And we might add—that will yield greater interchangeability of information. For the fourth and harshest lesson from agriculture is that we should make strenuous efforts now, before it is too late, to prevent further entrenchment of local experimental and analytical procedures

that change abruptly at state or province boundaries and could forever after inhibit interchange of specific data and full cooperation.

Response to these and similar lessons seems a worthy regional objective. In fact, without such effort we are unlikely to achieve other objectives fully or economically. Our resources are small in comparison with the needs we foresee.

This brings me to the last objective on my list. Southern U.S. and the West Coast of the U.S. and British Columbia offer us examples of highly effective cooperation in forest-fertilization investigations by industry, universities, and public agencies. In the next 2 days, we will hear more about the cooperative effort in eastern Canada. It is unlikely that our region will ever be united by a common funding source. Yet our conference here reflects a similar recognition of common problems too large and diverse for any small group to solve, and of the need to exchange information. In these 3 days we will make only a beginning at this exchange. Yet is a magnificent beginning and I suggest that we build upon it.

By this I mean more than planning for some future conference. Why not definite mechanisms for more rapid communication among all workers within the area? Why not efforts to standardize or coordinate the multiplicity of analytical procedures? Why not encouragement to specific agencies or task forces to attack region-wide problems such as those of efficient experimental design and technique? And with such things why not a much greater degree of technical consultation and collaboration among individuals and agencies than we have had in the past, perhaps leading to joint action or shared responsibilities in situations of mutual interest?

I suggest this conference consider formation of a central coordinating committee or, better, a regional forest-fertilization council with the aim of furthering

cooperation within and across state and provincial borders.

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GENERAL ENVIRONMENTAL AND BIOLOGICAL CONCERNS IN RELATION TO FOREST FERTILIZATION

by GORDON F. WEETMAN and STUART B. HILL, respectively Faculty of Forestry, University of New Brunswick, Fredericton, N. B.; and Department of Entomology, Macdonald College of McGill University, Ste. Anne de Bellevue, P. Q.

ABSTRACT. Forest fertilization, unlike agricultural fertilization, adds nutrients to relatively stable natural ecosystems in which there is an annual recycling of nutrients through humus decomposition. Not only can the new nutrient additions have direct effects on tree and other plant growth; but because the primary productivity is changed, all the consumers and decomposers in the ecosystem can also be modified. The authors outline the probable magnitude and direction of these changes, which, because of the complexity of food chains and organism interactions, may be both immediate and long-term and both local and wide-spread.

WE WILL attempt to give an overview of the effects of fertilization in established forests and plantations, with particular emphasis on N applications to northern temperate forests. The effects on nursery soils are not considered. Trends in forest fertilization have been reviewed recently by Bengston (1971). Much of the earlier European work on environmental effects of forest fertilization has been reviewed by Baule and Fricker (1970).

The topic is broad, and many aspects are poorly understood. Forest fertilization involves the periodic application of organic and inorganic fertilizers to relatively intact and stable forest ecosys-

tems. Our knowledge of the dynamics of forest ecosystems, particularly the natural patterns of nutrient uptake and turnover and the relationships between primary producers, consumers, and decomposers, is poor; and our knowledge of the effects of artificial manipulation of nutrient relationships is even poorer.

Consequently caution is required in the use of chemical fertilizers. Why caution? Much attention has been given to the effects of insecticide and herbicide use in forests, particularly with reference to their persistence, dispersal to other environments, effects on nontarget organisms, and accumulation in food chains (Rudd 1964). In contrast with these ma-

terials, the commonly used N, P, and K fertilizers have well-known and comparatively safe chemical properties. On the basis of our understanding of their agronomic uses, it might be assumed that their use in forests will be comparatively safe.

Up to the present, most of the concern about their use has centered around possible leaching losses of N (TVA 1969) and the toxic effects due to ingestion by forest animals (*Friburg* 1971). Overrein (1970), after examining the environmental effects of forest fertilization in Norway, concluded that, though harmful effects do not seem to have been caused up to now, widespread increases in forest fertilization could result in damage. It is possible, however, that the effects may be much more profound, long-lasting, and more potentially serious than would appear at first glance.

In agriculture, fertilizers are usually added to tilled mineral soils for a single-season effect in relatively large and frequent doses. In contrast, use in forests usually involves a modest application every 3 to 10 years to the surface of an intact forest floor over an undisturbed soil profile in an ecosystem in a relatively steady-state condition. The aim is to increase the productivity of the primary producers, trees, for as many years as possible by augmenting the natural supply of available nutrients.

We do not usually know the primary productivity of the site, nor do we understand the factors that control the natural supply of nutrients to stands of forest trees. We do not even have a soil-chemical analysis technique for forest soils that will enable us to relate fertilizer response by trees to the added N, P, or K.

Consequently our use of fertilizers in forests is still largely empirical and clumsy. It is clear, however, that when fertilizers are used, a large number of changes take place both within and outside the forest. These changes may be

drastic and persistent, because the primary productivity—and all food chains and tropic levels related to it (*Woodwell* 1970)—are all changed, often for many years, in some instances very radically. Not only are individuals changed, but the dynamics of the community are changed. Data on these changes are so sketchy and so limited to special situations that the best that can be done is to review what is known and speculate about the rest.

What makes the use of fertilizers in the forest seem alarming is that any current analysis of their effects must be based on so much speculation. The degree of caution and concern depends on a professional and scientific judgment as to whether the primary productivity in any individual forest ecosystem can be changed by chemical means without in turn producing some change that is either undesirable for humans or for the long-term integrity, stability, and productivity of the forest.

CONSEQUENCES OF FERTILIZER PRODUCTION

Beaton and Tisdale (1969) have estimated that 2,000,000 acres of forest could be fertilized annually in North America, and that this would require 87,000 tons of N, 39,000 tons of P_2O_5 , and 24,000 tons of K_2O . Current (1970) total fertilizer use in the U.S. is: N, 7.5 million tons; P_2O_5 , 4.3 million tons; and K.O., 4.3 million tons (*Harre* 1971). North American fertilizer companies faced with recent over-production, particularly of N, are promoting forest fertilization both by lowering fertilizer cost and by supporting research.

In contrast, some ecologically oriented people view the growth of the fertilizer industry with some alarm (*Commoner* 1968). Except for occasional use to aid in rapid revegetation of burned or disturbed areas (*Hakala et al.* 1971), the only motive for forest fertilization is

increased profit from forest products. This profitability is now possible in certain locations because of the improved demand-price situation, increased land prices, and decreased fertilizer prices (*Bengston 1971*). It is outside the scope of this paper to consider all the environmental consequences of increased fertilizer production. Only two points will be considered: research and energy.

Forest-fertilization research has required and will require considerable expenditures of money, materials, and energy. It has become a separate scientific discipline, and in terms of human ecology it could be considered a minor industry supporting the livelihoods of a few hundred people in North America—government, industry, and universities. Because of the long-term nature of experiments, sustained inputs of money, materials, and energy resources will be required to provide the scientific basis that will allow full use of this new silvicultural tool.

Energy is needed to manufacture fertilizers. Nicol (1967) estimated that the energy contained in 5 tons of coal is needed to make 1 ton of N fertilizer. One Canadian plant uses 35,000 SCF (standard cubic feet) of natural gas for every ton of ammonia produced. Natural gas is both the raw material and energy source for ammonium and urea fertilizers currently used here in forest fertilization. For the same plant, 176 kilowatt-hours of electricity are also needed per ton of ammonia. (Sloan, D. Can. Indus. Ltd. Cent. Res. Lab., McMasterville, P. Q., personal communication, 1972).

One may ask whether it is desirable to use energy on this scale to produce wood. If some of the more dire predictions about energy resources come true—for example, that 80 percent of U. S. fossil fuels will be exhausted within the next 100 years (*Hubbert 1969*)—then the price of energy may well increase much faster than the price of the wood produced through conversion of fossil fuels into am-

monium fertilizers. The development of a new technology that enables us to develop fertilizers from a nonrenewable resource, natural gas, has created the possibility of boosting the productivity of a renewable resource, trees. The economics of the technology involved and the future reserves of energy and P and K raw materials must be considered in evaluating the long-term prospects for forest fertilization.

A rough calculation of energy conversion shows that 35,000 SCF of gas at 1,000 B.t.u./SCF and density 0.61 contains 21 million B.t.u. A ton of ammonia converted to urea (34:60) and spread at 400 pounds/acre on 5 acres of spruce forest growing at 40 cubic feet per acre per year may produce an extra 600 cubic feet of wood in 10 years. At 200,000 B.t.u. per cubic foot, this extra wood contains 120 million B.t.u., a six fold energy gain. Alternatively, 21 million B.t.u. of energy have been used to concentrate on 5 acres the growth that would have occurred on 6.5 acres.

Gough and Eastlund (1971) have pointed out that, in industrially developed countries, energy sources open the gate to more efficient utilization of the sun's energy. This is only part of the energy story. Energy is required for plant development and maintenance, for advertising, storing, distributing, and applying the fertilizer, and for the research and education that its use necessitates. Indeed, we must include the total amount of energy that has been used to put on, and to transport us to and from, this Symposium!

IMPLICATIONS FOR FOREST MANAGEMENT

Before we deal with specific environmental and biological effects, consider some general effects on the whole forest or landscape that influence management practice.

There are two major types of large-

scale fertilization: (1) fertilization at the time of, or soon after, stand establishment, usually using one or more of N, P, and K, as used in peatlands of Scandinavia, British moorlands, in the Lower Coastal Plain of the southeastern United States, and in certain areas of Australia and New Zealand; (2) fertilization of middle-aged and older closed stands, usually using N alone, as used in the Pacific Northwest and on upland soils in Scandinavia (*Bengston 1971; Hagner 1971*).

Both types of fertilization increase site quality suddenly, involving initial temporary shocks followed by more gradual biological and silvicultural adjustment. For the first time, the forest land manager has the ability to increase the absolute productivity of a site. All other silvicultural practices merely change the timing and form of the forest crop.

The potential productivity of the forest is greatly increased. Management priorities must be adjusted to allow the concentration of effort on the potentially most productive land. Forest land must be classified for its potential to respond to fertilization, and new growth-rate calculations must be made. Unresponsive and low-potential lands may be released from timber production and made available for recreation and wildlife management, though the tendency of wildlife to prefer browse growing on the most fertile soil can pose problems.

Wood-procurement areas can be reduced by concentrating intensive management practices on accessible, responsive, and productive forest sites. Short rotations, site preparation, more roads, more protection, responsive species and genotypes, and thinning practices must all be reassessed for their relationship to fertilization in increasing productivity in specific forest conditions.

EFFECTS ON LIVING ENVIRONMENT: TARGET ORGANISMS: TREES

Most of the studies of forest fertilization have dealt with effects on tree growth. Less attention has been given to the competitive position of species in mixed stands, increased stand density, shading, and mortality (*Mustanoja and Leaf 1965*). It has been speculated that fertilizer application may increase competition and cause trees to express dominance faster.

This is a factor of some importance, particularly here in the Northeast, where conifer stands are often excessively dense and contain many unmerchantable stems of both conifers and hardwoods. Such stands are not attractive for fertilization because so much of the fertilizer investment goes into unmerchantable stems. This situation has led to establishment of several fertilizer trials involving cleaning or thinning to ensure that only potentially merchantable trees are fertilized. One such trial in black spruce indicated that N fertilization and thinning have given separate and additive beneficial effects (*Weetman 1971*).

With the exception of K responses in old fields (*Stone and Leaf 1967; Fornes et al. 1970*) most fertilizer response in established stands in the Northeast has been associated with the application of N. Since foliar N concentration and chlorophyll concentration are closely related (*Keller 1967*), and there appears to be a generalized N deficiency on podzolic soils, N applications usually result in larger, heavier, and darker green leaves on trees, a feature of great importance in Christmas tree production (*White 1968*). In closed stands, increased shading results; whether or not suppressed trees can respond to the applications may be related to understory light levels (*Brix 1971*) and to the tolerance of the species concerned. Consequently, on such a basis N applications might be expected to increase mortality in stands of intolerant

trees, whereas in stands of tolerant species all crown classes may respond equally.

The general relationships among leaf size, nutrient content, and flower and seed production are not clear. Though fertilization has increased seed production (Armson 1968), the reasons for the response and its consistency are not well understood. With seed production assured, however, N fertilization may greatly improve conditions for germination and establishment of spruce and fir forests by killing moss vegetation on the forest floor.

The N deficiency in northern forests is associated with the accumulation of organic N reserves, low N mineralization rates, and strong biological competition for N after stand closure (Romell 1935; Weetman 1962; Heilman 1966). Higher N mineralization rates in the humus tend to be associated with increasing quantities of herbaceous vegetation and increasing site productivity (Linteau 1955; Heilman 1966). After clearcutting, which removes much of the competition for N, there is a rapid release of mineral and other nutrients, the so-called "assart-effect" of Romell (Romell 1935; Tamm 1964, 1969), and a vigorous growth of pioneer vegetation. Natural or artificial reproduction of trees with low unit area N demand, growing under such conditions, may not respond to fertilizer applications (Roberge et al. 1970). Poisoning of the pioneer vegetation at this stage of development, as was done at Hubbard Brook, N. H., may lead to leaching losses of N (Likens et al. 1969).

The uptake of fertilizers by trees is relatively modest, particularly of N, because plants in general are poor competitors against the soil heterotrophic and nitrifying microflora for the assimilation of N (Jansson 1958). Studies of ^{15}N -labelled fertilizer uptake by conifers have indicated only a 3- to 23-percent uptake of added N. Thus, relatively little N is added to the above-ground portions of

the N cycle. The low uptake figures are no basis for concluding that a large portion of the balance of the added N is lost by leaching; in fact, this does not seem to be the case. Additions of K have been shown in red pine to be recycled and have long-lasting effects. However, N taken up generally has only a temporary effect on growth and is not rapidly recycled, but becomes incorporated into the organic matter, as does added P.

The effects of fertilizer uptake and associated increased production of photosynthate in relation to our understanding of how wood is laid down on trees has been examined by Larson (1969). Sudden increases in crown weights increase wind loads and thus modify stem form. Fertilization of young trees can be expected to increase the proportion of less desirable core or juvenile wood in the merchantable stem, to increase crown and branch size, and to delay natural pruning.

The early-wood/late-wood proportions in the annual ring depend largely on the distance from the leaves and tree base to the point at which xylem cells are laid down. Thus trees of differing live-crown ratios can be expected to respond differently to fertilization. In pole stands, moderate fertilization increases both early- and late-wood growth, with relatively little change in wood quality. Forest fertilization may also influence the resistance of trees to drought, frost, smoke, and other pollutants. K applications have resulted in increased frost resistance. (Baule and Fricker 1970).

EFFECT ON LIVING ENVIRONMENT: NONTARGET ORGANISMS

The effects of forest fertilization on the organisms associated with the trees depend on:

- Amount and composition of the fertilizer being applied (major nutrients,

- trace elements, and impurities) and time and uniformity of application.
- Soil properties (size of available and unavailable nutrient pools, pH, and rates of mobilization/immobilization).
 - Tree properties (any nutritional imbalance and deficiencies, also tree age, species, crown location, and exposure of foliage, etc.).
 - Food and space preferences of the resident organisms.

- Availability of organisms that would be favored by changes in food and space properties resulting from fertilization.

Non-Tree Vegetation

Fertilizer applications tend to be toxic to mosses and stimulating to other vegetation. Particularly where the "assart effect" is not operative, fertilization may greatly increase brush and ground-cover competition. In plantations, stimulation of grass and ericaceous vegetation may be detrimental to tree growth, but may greatly improve its palatability as browse. These difficulties have led to increased use of selective placement and slow-release fertilizer packages in plantation establishment (White 1968).

At excessive rates of application, vegetation may be burned. At more moderate rates, ground vegetation similar to that on clearcut conditions (for example, *Erythronium angustifolium*) may develop inside forest stands. At practical levels, N fertilization usually appears to have little effect on ground vegetation in closed stands. P and K fertilization of peats affects the vegetation for a much longer period.

Mycorrhizae, Symbiotic, and Non-Symbiotic N Fixers

As mycorrhizae are usually most active in soils with low N and low pH, fertilization invariably depresses them. This ef-

fect is most pronounced at the time of natural inoculation (Göbl and Platzer 1967).

As mycorrhizal development is probably determined primarily by the internal nutrient status of the plant (Hatch 1937), the application of fertilizers as foliar sprays may be expected to be as damaging to mycorrhizae as when they are applied to soil. The instances where fertilizers have improved or not impaired mycorrhizal development have invariably been on leached sandy soils (Koberg 1966; Kumar et al. 1968). The mechanisms involved have been discussed by Harley (1969). However, it should be noted that most of the studies on which the above statements are based were carried out in nursery or pot soils, being managed more like agricultural than forest soils. The lower frequency of fertilizer applications in established stands, coupled with the low level of disturbance at time of application, will have the effect of reducing the harmful effects of fertilization on mycorrhizae.

N fixation by symbiotic and nonsymbiotic N fixers in forest soils will undoubtedly be inhibited by N fertilization (Allos and Bartholemew 1959; Delwiche and Wijler 1956). At present this loss of N is regarded as unimportant because of the low cost of N fertilizer.

Decomposer Microorganisms

Fertilizers have a direct effect on soil microorganisms by altering the pH, C:N ratio, or other nutrient conditions in the soil, and an indirect effect via increased litter fall.

Because of the difficulties in estimating densities of soil microorganisms and distinguishing between active and inactive stages, most studies have been of an indirect nature, concerned with the rates of N mobilization/immobilization and the release of various gases and enzymes.

Studies to examine species changes include those of Corke (1959), Reddy and

Knowles (1965), Schalin (1967), Mai and Fielder (1968, 1969a, 1969b, 1970), Kastner and Fielder (1970), Peterson (1970), and Roberge *et al.* (1970). The studies of Roberge and Knowles (1966, 1967a, 1967b) have demonstrated increases in ureolytic microorganisms after the application of urea. The significance of most of the other observed changes are hard to assess. More revealing are the studies on the associated changes in N mobilization/immobilization, changes in nutrient release due to a "priming effect", and in rates of nutrient cycling. These processes are usually increased as a result of fertilization (Parr 1968), which can consequently be viewed as beneficial, at least in the short term.

The long-term implications of such changes are difficult to assess. In view of the differences between forestry and agricultural operations, it seems unlikely that forest soils will suffer from the reduction in organic matter content that has invariably accompanied the use of fertilizers on agricultural soils. Indeed it is likely that in some locations organic-matter content of the soil will increase because of the increased ability of fertilized trees to capture the sun's energy and fix carbon. The long-lasting effects of fertilization on decomposers are discussed by Franz and Loub (1959), who found that the beneficial changes in soil microflora brought about by the application of CaCO_3 were still evident 50 years later.

Soil Fauna

Apart from the brief reviews by Mustanoja and Leaf (1965) and Baule and Fricker (1970) there has been no general review in English of the effects of forest fertilization on soil fauna. There is, however, an extensive Russian study on the general ways of regulating soil fauna in forests (Lavrov 1968).

In the same way that soil microbial populations frequently make up a greater biomass than primary producers, so also

can soil faunal populations make up a greater biomass than above-ground consumers; and their role in soil has been shown to be more important than their biomass would indicate (Macfadyen 1961, 1964; Witkamp 1971). In view of the importance of the soil fauna, it is surprising that there have been so few studies on the effects on them of such management practices as fertilization. Fewer than a dozen comprehensive studies have actually been carried out.

When fertilization increases soil porosity and microbial activity by lowering pH and/or by supplying limiting nutrients, the density, and often the diversity, of the soil fauna increases. Most of the qualitative changes are related to the fertilizer's effect on the balance between bacteria and fungi.

Increases in density have been shown for nematodes, enchytraeids, lumbricids, mites, and Collembola. Studies covering all or most of these groups have usually also demonstrated increases. In most cases the increases have occurred gradually over 4 or 5 years and have persisted for up to another 5 years (Aaltonen 1940; Franz 1953). This indicates the need for long-term studies.

The lasting effects of fertilization for trees are probably due largely to the mutually beneficial relationship between the soil microflora and fauna. The microflora provide the fauna with suitable food and the fauna provide the microflora with space by transporting their spores to suitable substrates.

Decreases in density after fertilizer application have been noted for plant parasitic and fungal feeding nematodes (Bassus 1967, 1968), cryptostigmatid mites (Ronde 1957; Franz 1957, 1959; Bassus 1960b; Märkel and Bösner 1960) and Collembola (Ronde 1960). In most of these instances, the fertilizer applied was lime, and the decreases could be correlated with a decrease in density of fungi, the food of most of these animals. However, trace element fertilizers have

been shown to drastically reduce cryptostigmatid mite populations in pasture soils, due probably to a direct effect (*Lesin'sh* 1970). With gaseous ammonia, Franz (1956) found that all groups were reduced.

These observations have been supported by laboratory studies on the toxicity of ammonia to mites (*Moursi* 1962, 1970). However, Zwolfer (1957) and Ronde (1961) found that all groups rapidly increased after forest fertilization with NH₃. In the only Canadian study, Behan (1972) recorded an initial decrease in density of mites and Collembola, followed by a fairly rapid increase. The decrease was probably due to a direct poisoning effect of the urea fertilizer used, and the increase was due to increased microbial activity. Laboratory studies on effects of fertilization on palatability of leaves to soil arthropods have been carried out by Biwer (1961). The complex relationship between the soil fauna and tree health and the ways in which this relationship might be affected by such factors as fertilization have been discussed by Schaefferberg (1953), Zwolfer (1957), and Schwenke *et al.* (1970).

Effects on Pests and Diseases

If the fertilizer corrects nutritional imbalance and deficiencies in the trees and brings them nearer to their optimum rate of growth, then there will usually be no increase in damage caused to the trees by organisms that feed on them. However, if nutritional imbalance is increased and rate of growth is taken beyond the optimum, then increased attack may be expected. It should be noted that the optimum rate of growth for the trees is likely to differ from the optimum rate of growth that we refer to in our fertilization cost : benefit equations. It would also be noted that damage to the tree is not directly related to the amount of it that is eaten, but rather to the tree's ability

to return to an optimum state after being attacked. Unfortunately most studies have been concerned with the extent of attack and density of the attackers rather than the damage done.

Insect and Mite Pests

The literature on the effects of forest fertilization on damage by insect pests has been reviewed in North America most recently by Mustanoja and Leaf (1965), Stark (1965), Lee (1968), Foster (1968) and Sharma (1970). The extensive German work has been reviewed by Schindler (1967) and Merker (1969).

For example, Foster (1968) noted that fertilization with N has been shown to decrease insect damage by increasing mortality of: (1) those sawfly and moth larvae that chew the foliage of forest trees, and (2) bark beetle larvae; and to increase insect and mite damage by increasing population densities of: (3) twig and shoot boring weevils and moth larvae, and (4) plant sucking bugs, aphids, and mites.

These findings have been explained by relating them to certain effects that fertilizers are known to have on trees and to certain other effects that they may have. These operate by changing the availability of suitable food and space for the pests (see tabulation).

Pests respond by changing their behavior, preferences, tolerance ranges, natality, mortality, longevity, rate of growth, ultimate size, etc. (*Singh* 1970).

The use of fertilizers to reduce insect damage is unlikely to become widespread: first because their controlling effect is usually slight compared to the cost of application; and second, though some pests may decrease, there will always be the danger that others will increase.

On the other hand, it is likely that many fertilization programs will be abandoned because of associated increases in pest damage (*Armson* 1968, p. 176).

Possible effects of fertilizers and their application on insect pests of forest trees

I. Decrease availability of suitable food by:

- a) Reducing percentage sugar in tree.
- b) Direct poisoning effect via food.
- c) Increasing resin and essential oil content of tree and/or by changing the composition of these materials in it.
- d) Accelerating growth and thereby enabling trees to pass through the susceptible stage faster.
- e) Changing osmotic pressure of host sap so it is above or below that of the insect.
- f) Changing amino acid composition of tree.
- g) Increasing lignification of host tissue.

II. Increase availability of suitable food by:

- a) Increasing percentage sugar in tree.
- b) Increasing biomass of tree and accelerating maturation.
- d) Changing osmotic pressure of host sap such that it is nearer to that of pest.
- e) Decreasing cuticle thickness.

III. Decrease availability of suitable space by:

- a) Promoting the release of repellent chemicals from the tree.
- b) Increasing turgor pressure and resin flow such that galleries and tunnels of borers become flooded.
- c) Modifying undergrowth so it can support more parasites and predators of pest.
- d) Contact poisoning effect by fertilizer or its impurities (e.g. biuret in urea).
- e) Physically removing pest when applying fertilizers as foliar sprays.

IV. Increase availability of suitable space by:

- a) Promoting the release of attractant chemicals or by decreasing the release of repellent chemicals from the tree.
- b) Modifying undergrowth so it cannot support sufficient predators and parasites of pest.

Disease Organisms

The effects of fertilizers on diseases of forest trees are no less variable than the effects on insects (*Donaubauer et al. 1967*). Where fertilization corrects deficiencies, disease is usually reduced; and where it creates them, disease often increases (*Mustanoja and Leaf 1965; Foster 1968*). N and N-P-K fertilizers have

been found to increase tree susceptibility to a number of fungi, including *Cronartium fusiforme*, certain *Fusarium* spp. and *Verticillium* spp., several rusts, and various fungi of poplars. Increases in diseases of seedlings are particularly common after fertilization. On the other hand, N fertilizers usually decrease attack by *Lophodermium pinastri* (pine needle cast), *Phytophthora cinnamomi* (littleleaf disease), *Ceratocystis ulmi* (Dutch elm disease), and *C. fagacearum* (oak wilt). After reviewing 120 studies on the effects of N fertilization on plant diseases, McNew (1960) commented that "... about the only conclusion that can be formulated is that excess nitrogen probably should be avoided but every disease has to be considered as a special case!"

Increases in pH after lime or NH₃ application have been found to increase damping-off and attack by *Fomes annosus*, though urea, which can also increase pH, has been used to control development of this fungus on stumps (Berry 1965).

K fertilization is usually more successful in reducing disease, especially in cases where N increases it.

Some of the ways in which fertilization can affect disease organisms have been discussed by McNew (1960), Sadasivan (1965), and Foster (1968), though much more work remains to be done before we can obtain a clear picture of the mechanisms involved. For example, fertilizers often increase the density of the undergrowth; this changes the climate above the ground, which in turn is likely to affect the growth and distribution of disease organisms. Very few studies have been carried out to examine these chain-like relationships.

Wildlife

The main findings to date are as follows:

1. Fertile soils support more wildlife (*Wilde 1946; Nagel 1952*).
2. When presented with a choice, wildlife select the most nutritious food (*Arnold 1964; Watson 1970; Dasmann 1971*).
3. Wildlife feed preferentially on browse that has been fertilized, rather in the same way that they feed preferentially on the highly nutritious shrubs that develop after a forest fire (*Dasmann 1964, 1971*).

Where several combinations of fertilizers have been tested, N alone or in combination with P and/or K has increased attack by wildlife more than has P and/or K or lime, the latter often having no effect (*Wood and Lindzey 1966*). Though all the studies cited above refer to mammals, particularly deer, similar findings have been recorded for birds (*Andersson et al. 1970; Friburg 1971; Miller 1968; Miller et al. 1970; Moss 1968, 1972*).

We have noted increased feeding by spruce grouse on fertilized black spruce in Quebec.

Friburg (1971) has reported on Finnish studies where moose, reindeer, and deer showed no interest in eating P-K or urea fertilizer. When mixed with moss, urea gave reindeer an upset stomach. After fertilizer has been spread in the forest, birds may swallow particles while looking for sand, though fairly large doses would be required to harm them. Some birds spat the fertilizer out and rapidly lost a taste for it.

EFFECT ON NON-LIVING ENVIRONMENT

Air-Gas Composition

Volatilization of added ammonium N has been shown to be appreciable, particularly when urea fertilizer results in increases in pH on dry forest floors (*Volk 1970; Bernier et al. 1972; Watkins et al.*

1972). There is also some evidence of loss of elemental N (*Nommik and Thorin 1971*). It is possible that some of the released ammonia may be picked up by vegetation in the forest. Carbon dioxide concentrations may also be temporarily increased after hydrolysis of added fertilizer by urease to carbamate, which breaks down to ammonia and carbon dioxide.

Water Composition

Losses of nitrate-N from corn fertilization (*Commoner 1971*) and from an unfertilized but herbicide-treated clearcut watershed at Hubbard Brook, N. H. (*Smith et al. 1968; Likens et al. 1969*) have attracted a lot of recent attention and critical comment. In contrast, a recent study showed that leaching losses of urea N fertilizer added to an intact forest ecosystem were very small (*Cole and Gessel 1965*).

Overrein (1968, 1969) has studied leaching losses for 12 weeks after applying urea, ammonia, and nitrate at 250 kg. N/ha. Leaching losses in the lysimeter in the acid forest soil were 1.6, 21.5, and 91.8 percent respectively of each form of added N. Nommik and Popovic (1971), using ^{15}N -labelled fertilizers on micro-plots exposed to weathering for 12 months, recovered 76, 63, and 23 percent of added urea, ammonium, and nitrate-N in the soil profiles. Similar ^{15}N labelling and uptake studies on black spruce (*Weetman et al. 1971; Lefebvre 1972*) confirmed that, of the three forms of N fertilizers, urea is the least subject to leaching losses.

Aerial urea fertilization of two forested creeks in Washington, about 2,000 acres in area, caused nitrate-N levels in the creeks to increase to a maximum of 1.32 p.p.m. 1 week after fertilization. Urea concentration increased on the day of application. Nitrate levels were back to pre-fertilization levels after 4 months (*McCall 1970*).

In Sweden, urea was applied at 250 kg. of urea/ha. around the perimeter of a forest lake; a total of 11 tons of N was applied. In the first summer after treatment only 30 to 40 kg. of N were found in the lake (0.6 mg./l. to 0.9 mg./l.) and in the second summer only 10 to 20 kg. (*Friburg 1971*).

Generally it appears that urea is well retained in the upper portions of the soil, while ammonium nitrate is less well retained. Nitrate-N is barely retained and is washed down into the mineral soil below the depth of rooting. The effects of increased nitrate-N levels in the water have not been demonstrated. Most forest sites can be considered good filters, which allows successful disposal of sewage by irrigation (*Wadleigh 1968*).

For peat sites P and K are generally used. Leaching of K does not present any drawbacks, whereas small increases in P concentration can increase vegetation growth in the water unfavorably. Research to date indicates that soluble P fertilizers can be leached easily, while non-soluble forms are not. Any difference in fertilizer effect between those types has not been observed (*Friburg 1971*).

Soil

Bengston (1970) has recently reviewed the effects of N and P additions on the forest floor. Only a small amount of added N is taken up by the trees; much of the balance increases the N cycling within the humus layer. The fate of added N, the changes in size of the N pool, and the "priming effect" of added fertilizer N on the mineralization of native organic N have been studied in acid raw humus soils in particular. These changes are of great practical importance because under these conditions the length and magnitude of the response by the trees is closely related to levels of ammonium-N in the humus layer. N fertilizer additions may increase P, K, Ca,

and Mg concentrations in humus leachates (*Beaton et al. 1969*).

The additions of ammonium-N to such soils turns the normally fibrous humus layer into a blacker and greasier condition. The significance of the change in physical state is uncertain; improved seedbed properties and increased water penetration may result. Concern over declining organic matter reserves due to N fertilization in agriculture would not seem to be appropriate on most forest soils that show N responses because many tend to suffer from excess organic-matter accumulations.

N fertilization may increase the solubility of organic matter and lead to increased deposition in the B horizon or even increases in organic matter in drainage water. Ogner (1972), who has studied the effects of urea on raw humus, noted that "physical chemical reactions" dominate the humic transformations. The formation of ammonium salts and increased pH leads to increased solubility, leaching of organic matter, and partial collapse of the physical structure. The significance of increases in the amount of non-hydrolyzable organic matter, with a higher N percentage, and losses of humus N compounds, carbohydrate materials, and lipophilic components on long-term soil productivity have yet to be assessed. Deposition of organic-N in the B-horizon may be of some value to future tree growth (*Tamm 1969*).

Phosphatic fertilizers, although little used in this region, have been found to improve soil physical properties and drainage, and to immobilize excess Al and Mn in Piedmont and Coastal Plain soils (*Bengston 1970*).

DISCUSSION AND CONCLUSIONS

As little attention was paid to forest fertilization before 1960, the study of its effects is relatively new in North Amer-

ica. The use of fertilizers in agriculture and forestry is very different, so the temptation to draw close parallels between agronomic and forest effects must be resisted.

The two major effects of forest fertilization of most concern are: (1) risks of general water pollution, and (2) general changes in the biology of forest ecosystems.

There is some reason to believe that, with care in application, the chances of serious groundwater pollution are slim because the forest floor is such a good natural filter.

There is less reason for confidence about changes in the biology of forests. Fertilization makes the forest look more vigorous, but a price may have to be paid in terms of unfavorable changes in the population density and dynamics of the other components of the ecosystem. The need for long-term and fundamental studies of forest systems cannot be ignored. With such a paucity of data, there is a danger that wide publicity of a few examples of unfavorable biological consequences due to fertilization may cause public opinion to inhibit forest-fertilization practice.

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A MULTIDISCIPLINARY APPROACH TO STAND-MANAGEMENT RESEARCH IN THE FOREST ECOSYSTEM

by C. P. BRETT, Head, Forestry Services Section,
Pacific Forest Research Centre, Canadian Forestry
Service, Department of the Environment, Victoria,
British Columbia.

ABSTRACT. The potential for effective results is good. The ecosystem in which an individual tree exists is not unmanageable. The resources and range of disciplines required to study it and other individual tree ecosystems intensively can be acquired and deployed without many of the difficulties encountered in studying forest ecosystems. Sampling techniques to provide a link between individual trees and the forest stand in which they exist are now being tested. Tree-growth models, vital to the development of analytical and predictive capacities we need, already exist, though at a low resolution.

Maintenance of a healthy and competitive forest industry in British Columbia is of great importance to local and national economies (*Nagle 1970*). The economic viability of this industry depends in part on the cost of acquiring, harvesting, and processing wood. This cost is rising as logging operations shift to less productive and lower quality stands at higher elevations and in the hinterlands. In spite of large timber reserves, local wood shortages are predicted, particularly in the coastal forest region. These shortages will become more acute if the diversion of forest land from timber-growing to other uses continues at present rates (*Worrell 1967*).

Consequently, it is essential that Brit-

ish Columbia move toward a management program in which attainment of optimum productivity of forest lands is stimulated. The British Columbia Forest Productivity Committee was recently created in recognition of this need, resulting in incentives offered in the form of increased allowable cuts to forest companies that implement certain tree improvement, spacing, thinning, or fertilization practices on public land. In acknowledgment of research needs, the Committee is also undertaking large-scale cooperative fertilization-thinning trials, covering the major soil and climatic regions in coastal British Columbia.

This paper outlines the rationale for the Pacific Forest Research Centre's

multidisciplinary research program to assist in the attainment of optimum productivity of forest lands; the status of the program, its inter-related studies, and its expectations.

RATIONALE

Where it was once possible to identify and solve most problems singly, it is now clear that there are growing interdependencies among people, their activities, and the environments in which these activities take place. These interdependencies are becoming critical factors in the implementation of new resource-development programs.

Questions of local and global population growth rates, resource availability and usage, and incidence of wastes or pollutants are no longer unrelated problems. They are realities today that we must learn to deal with. To paraphrase Reichle (1970), our challenge to meet increasing wood needs will require optimization of the productivity of managed forest ecosystems with minimal degradation of environmental quality. In the light of only a few of our problems, this is indeed a lofty challenge.

Forest fertilization and thinning are merely two of several general ways of manipulating forest ecosystems. They must be considered in terms of complex chemical, physical, and biological interrelationships if we expect to explain the wide variation of response to such treatments, and if we are to extrapolate research results.

Unexplained variation is seen in the results of many field trials. Although promising, these results have not provided the kind of predictive ability required to improve wood yields, ensure environmental stability over a range of forest types, and recommend management practices or prescriptions.

The complex inter-relationships of factors involved in determining biological productivity are not completely identi-

fied, let alone understood. Our knowledge varies from one discipline to another. Sampling techniques, instrumentation, and predictive tools are of variable quality and usefulness and, in general, are inadequate.

In British Columbia, other problems are raised by the extreme variation of local topography, climate, and soils. Almost every conceivable physical feature is represented. Climate ranges from cool, high precipitation coastal regions to hot, arid desert lands. Soils are mainly young and of glacial origin. They have poorly developed profiles and are extremely variable. This wide range of conditions has led to development of a corresponding plethora of plant and animal associations.

How can we achieve a better understanding of basic growth processes and thereby develop effective and environmentally acceptable cultural practices in view of the low state of knowledge, the extreme variability of B.C. forests, and their chemical, physical, and biological complexity? Consideration of all the preceding factors indicates, first, that only a multidisciplinary project team, supported by provincial government and industrial forest cooperators, is likely to produce effective results in reasonable time at a realistic cost.

Second, all questions cannot be answered simultaneously. Initial trials must be flexible to accommodate the establishment of closely related studies in tree physiology, soil chemistry, land classification, soil micro- and macrobiology, climatology, pathology, entomology, and mensuration. The trials must also cover a range of treatments that have some relevance to future management practices and, by changing the forest environment, provide a basis for explaining some of the factors involved in these changes.

Third, extensive effort must be expended on the development, testing, and refinement of sampling techniques, instrumentation, and predictive tools. Existing stand-sampling techniques are not

adequate. Unless sample size can be reduced and refined, we cannot afford the expense of studying enough of the pertinent variables at one time. In addition, we cannot find sufficient homogeneous areas of a size in which traditional trials may be carried out.

Also, we need a better means by which growth-limiting factors affecting tree-growth response may be defined. At present, we know that many site, tree, and stand parameters integrate growth factors; but we cannot characterize the specific components and we do not understand their relative importance. Finally, we need a predictive ability with high resolution if we are to assess the many possible management practices in light of great variation and complexity.

The importance of development and refinement of sampling techniques and tree-growth models cannot be overestimated. We must have these research tools in usable form if our multidisciplinary team is to make significant moves beyond the limitations of present investigations.

PRESENT PROGRAM

The objectives of the program in its initial phase are:

- To explain the effects of N fertilization on the quantity and quality of tree growth under different stand-density levels, and to study how climatic and edaphic factors affect N availability and tree response.
- To develop a better definition of growth-limiting factors presently integrated under site and tree or stand condition.
- To build a basis, through the development of sampling and predictive tools, for measurement and interpretation of biological, physical, and environmental factors over a wide range of site, age, density, and species types.

The main organizational mechanism through which our multidisciplinary program is operating is a common study area in a 26-year-old Douglas-fir plantation on a medium- to low-site glacial till, near Shawnigan Lake, British Columbia. According to Krajina (1965), this area is included in the biogeoclimatic subzone Madrono-Douglas-fir, which is a part of the coastal Douglas-fir zone.

The climate is Mediterranean subhumid. Mean annual temperature is 49°F. and precipitation 46.2 inches. Average winter snowfall is 34.5 inches. The area is characterized by regular spring or summer droughts of 4 to 8 weeks' duration.

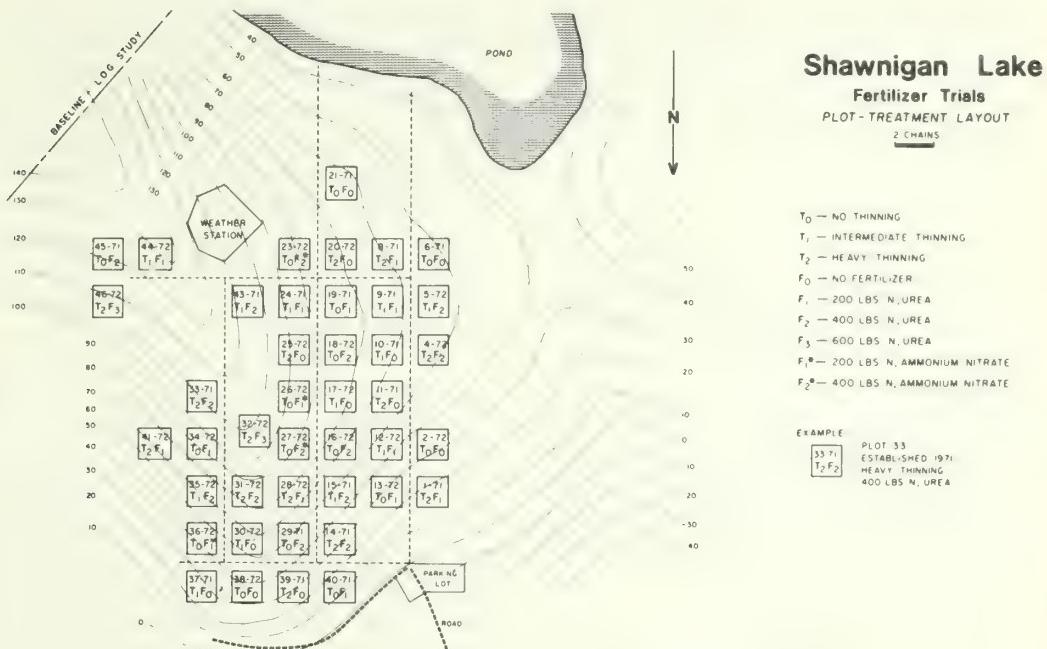
The study imposes fertilization and thinning treatments at several levels, singly and combined, in each of two successive years (fig. 1). It begins with the commonly used N fertilizers urea and ammonium nitrate.

As of 1 April 1972, 36 one-fifth-acre plots, each with a 33-foot buffer zone, were established. Treatments imposed on 18 plots during 1971 and 18 plots during 1972 were:

- Three levels of growing space, ranging from unthinned controls to open-grown trees.
 - Three levels of N in the form of urea at 0, 200, and 400 pounds N per acre.
- Six additional plots were established in 1972 and treated as follows:
- Two plots thinned to an open-grown condition and treated with 600 pounds N per acre in the form of urea.
 - Four unthinned plots, two treated with ammonium nitrate at the rate of 200 pounds N per acre, and two at the rate of 400 pounds N per acre, also in the form of ammonium nitrate.

By manipulating several N and stand-density levels, we hope to explain changes in the forest environment in terms of tree growth and tree-growth

Figure 1.—Plot-treatment layout for Shawnigan Lake fertilizer trials.



processes, and from field and laboratory studies to interpret important soil and climatic factors relative to tree growth. The knowledge and experience gained should lead to a better definition of growth-limiting factors which, in quantifiable form, can be utilized in the development of a biologically-based tree-growth model (fig. 2).

The results of the Shawnigan Lake studies and the concurrent development of both a growth model and a more efficient sampling design should lead to studies covering a wider and more comprehensive range of conditions. Consequently, a greater variety of sites and treatments can be selected in future trials, in cooperation with the British Columbia Forest Productivity Committee. Such coverage will enable testing of the knowledge gained at Shawnigan Lake and in the laboratory and will facilitate further development of growth-prediction models.

At present our studies are designed to

PROJECT STRATEGY : FLOW DIAGRAM OF AREAS OF STUDY , STUDIES INTERACTIONS

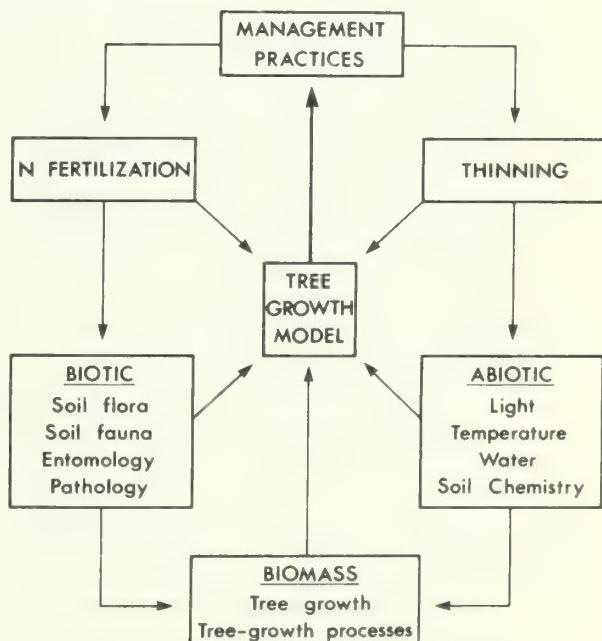


Figure 2.—Flow diagram of areas of study and study interactions.

assess the availability and the utilization of N, and to develop sampling techniques and a tree-growth model. The main Shawnigan Lake studies are described later in more detail.

Availability of Nitrogen

In the first group, studies are directed toward explaining the immediate and long-term effects of applied N treatments on N availability to trees and other vegetation. Studies of immediate N effects are: N uptake, leaching and runoff, volatilization and immobilization by soil, soil flora, and fauna. Studies of the longer term effects of applied N are covered under N cycling: retention, redistribution, and soil storage.

Utilization of Nitrogen

In the second group, the studies are designed to explain and quantify tree growth in terms of physiological processes and conditions resulting from interaction of available N and other growth-limiting factors. Studies of these other growth-limiting factors are: light, air and soil temperature, precipitation and soil water, and other nutrients. In addition to measuring these factors under natural conditions, the studies include investigation of changes under controlled conditions in the laboratory and under field situations through such stand treatments as irrigation and thinning.

Sampling Techniques/ Growth-Model Development

In the final group, studies are to test and refine an individual tree-plot sampling design recently developed by Arney (1972a) to investigate and develop means of quantifying growth-limiting factors, which would enable their testing as components in tree-growth models; to test existing tree-growth models such as those of Arney (1972b), Bella (1970), Lee (1967), and Lin (1969); to further

develop and refine appropriate tree-growth models on the basis of knowledge acquired as a result of the Shawnigan Lake studies and those carried out in the future; and finally, to use the models after initial testing to measure the efficacy of the kind and number of components required to predict accurately tree growth and quality.

A brief description of seven major Shawnigan Lake studies follows:

1. *Pilot fertilization trials of coastal Douglas-fir and western hemlock. (C. P. Brett)*

The objectives of this study are to measure volume growth response of managed stands to N fertilizer applied to specified sites and stand conditions; to assist, coordinate, and keep in phase the supportive efforts of researchers working in related projects, and to assist in development, refinement, and testing of individual tree-plot sampling techniques, tools, and tree-growth models.

The main responsibilities within this study have been to establish and maintain the study area (described previously) near Shawnigan Lake, British Columbia, and to facilitate the efforts of associate researchers.

Tree measurements on the 42 plots include location, d.b.h. (to 1/100th inch), height to live crown, crown class, crown quality, and cone-bearing status. Tree heights were taken in conjunction with a tree physiology study on 6 trees per plot, and with a tree-form study on 10 trees per plot. In addition, 144 tree heights on selected plots were measured in conjunction with the individual tree plot design study.

To acquire pre- and post-thinning data for crown mapping and tree-height measurements essential for use in stand growth model utilization (Mitchell 1969), low level 70-mm. fixed-base aerial photographs were taken at appropriate times.

A meteorological station was estab-

lished on site in April 1970. This station is equipped with a 30-day hygrothermograph, rainfall recorder, snow gage, total precipitation gage, solar radiation recorder, and recording anemometer. Stem analyses were carried out on selected trees before treatment.

2. *Nutrient distribution of a young Douglas-fir ecosystem.* (B. D. Webber)

To provide pre-treatment characterization of total above-ground biomass and of nutrient distribution, sampling has been carried out in selected plots on the Shawnigan Lake site.

3. *The physiology of growth of Douglas-fir in relation to nitrogen fertilization and thinning.* (H. Brix)

The purpose of this study is to find criteria for prediction of growth responses to stand thinning and N fertilization by providing knowledge of environmental conditions and physiological mechanisms associated with the growth response.

Several team studies are concerned with factors that affect the availability of N to the tree. This study aims at defining stand and environmental conditions that influence the growth response of trees when their N content has been increased. The study, which began in 1967 in the laboratory and at the Greater Victoria watershed, sought to clarify whether fertilization affects stem growth by influencing the amount of leaves produced, the productivity of the leaves, or both (Brix and Ebell 1969 and Brix 1971). In the first case, it is clear that only stands with leaf masses below the optimum will benefit from fertilization. In the latter case, the processes by which productivity of leaves is affected should be known, and interactions with environmental factors such as light, temperature, and water should also be investigated to predict the growth response of a stand to fertilization.

Rates of photosynthesis and respira-

tion have been measured in the laboratory in relation to light intensity and leaf water potential for trees receiving different N regimes. Stand treatments such as irrigation and thinning, with or without fertilization, have further aided in explaining physiological aspects of N fertilization.

4. *The role of soil fauna in tree nutrition and forest fertilization.* (V. G. Marshall)

This study is to determine the effects of fertilizers and thinning on natural soil faunal populations, and to elucidate food chains of the dominant animals and ascertain their role in nutrient cycling. The long-range goal is to indicate the possible means of manipulating the soil fauna that favorably influence soil fertility and increase tree growth.

Soil faunal populations are being studied, and measurements of CO₂ evolution, pH, soil temperature, soil moisture, and organic-matter decomposition are being taken. Pilot greenhouse experiments have been initiated to evaluate ¹⁵N techniques for a proposed major collaborative study.

5. *Microflora and biotic processes in managed forest land.* (J. Dangerfield)

This study seeks to determine the effect of various management practices on the soil microflora and associated biological processes, and the significance of this effect on nutrient availability and forest productivity. The long-range goal is to develop guidelines outlining the combined soil conditions and management practices likely to produce desirable biotic effects.

Thinning and fertilization effects will be evaluated by conducting a specific microfloral characterization, determining the potential of mixed soil flora to perform selected organic and inorganic transformations, and monitoring soil enzyme levels (cellulose, protease, phytase,

urease, dehydrogenase). This will provide information for the data pool, to develop a meaningful explanation of these effects on plant productivity.

6. Nitrogen movement and urea-induced transformations in forest soils. (B. D. Webber)

The study is to characterise the soil N cycle and transformations, and the effect that urea fertilization has upon them.

Lysimetry sampling, after Cole and Gessel (1968), has been undertaken at all levels of fertilization both in medium-thinning 1971 plots and unthinned and heavily thinned 1972 plots. There is continuous monitoring of soil temperature, moisture, and pH. Attempts have been made to measure volatilization losses immediately after fertilizer applications in 1971 and 1972.

7. Treatment responses of individual trees as a basis for prediction of growth and yield of managed stands in coastal B.C. (J. Arney)

The objectives of this study are to quantify and develop models of the basic components of tree and stand growth, and to provide a basis for predicting stand-volume growth response from one period to another.

Individual tree-volume growth predictions will come from inputs from potential tree growth (present stem volume and crown dimensions) and, initially, from environmental constraints (present age, site index, and degree of surrounding competition). At this stage, the model has a low resolution. A higher resolution is expected in the future as growth-limiting factors are defined more clearly and can be utilized by the model.

Studies of individual trees, however, will have limited meaning to resource managers unless a clear growth and volume relationship is established between

trees and forest stands. A promising approach to this problem has been developed by Arney following procedures similar to Keister (1971) and Lin. Individual trees have been located on 9 one-fifth-acre plots covering 3 levels of fertilizer application, 5 levels of competition and 2 levels of thinning release. Only 48 trees are required for each fertilization rate, including four replications.

With plot stand tables and stem maps (both required for calculating a competition index for all plot trees), and assuming that individual tree data within each of the five competition levels represent the average for their respective classes, the data can be expanded to a plot basis. This means that one of the 18-plot Shawnigan Lake installations covering 3 levels of fertilization and 3 levels of density replicated only twice could be replaced by a 2- to 3-acre installation in which only 144 trees were measured intensively.

Associated Studies and Consultants

Several other researchers at the Pacific Forest Research Centre are associated with the program through their related studies in forest fertilization and thinning before organization of this program, or through their expertise in a range of disciplines. Lee (1968, 1970, 1971) and Carrow (1971) have extended their studies to the Shawnigan Lake site to determine the effects of thinning and fertilization on tree form and on black-headed budworm populations, respectively. Diggle (1971) has established a long-term thinning study in the same plantation immediately adjacent to the fertilizer-thinning installations.

Other consultants include a pathologist, a soil scientist, a seed and cone entomologist, a meteorologist, an economist, and a biometrician.

CONCLUSION

The approach taken is based on the realization that we are obliged to reach for optimum productivity on forest lands, but there is little hope that we can approach this goal unless we commit ourselves to systematic investigations designed to achieve a growing understanding of biological productivity.

At present, the program reflects a concentration of effort in one place on field trials of limited design. However, this step is seen primarily as a preparation necessary for constructing a firm base before embarking on an adventurous but deliberate path through a maze of biological complexities.

The potential for meaningful results is good. The ecosystem in which an individual tree exists is not of unmanageable proportions. The resources and expertise required to study it and other individual tree-ecosystems intensively can be acquired and deployed without the extreme difficulties encountered in studying forest ecosystems.

Sampling techniques, which can provide a linkage between individual trees and the forest stand in which they exist, have been designed and are now being tested. Finally, tree-growth models, vital to the development of analytical and predictive capacities we need, already exist, albeit at a low resolution.

At present, there is a priority to test, on other sites and age classes, knowledge now being acquired. Other aspects of fertilization to be studied are: other N sources, time of application, other rates, repeated application, and various fertilizer combinations. Other related studies include: the role of mycorrhiza in nutrient uptake, the use of ^{15}N -tagged fertilizers to elucidate applied N pathways, and the affects of proposed intensive management practices on wood quality.

Knowledge and experience gained from closely related studies at the Shawnigan Lake site and in the laboratory—along

with the concurrent and integrated development of sampling and predictive tools—are expected to lead to a better definition of future research needs and the increased probability that we can develop the technology to fulfill these needs and, ultimately, to the development of management prescriptions.

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ECONOMIC CONSIDERATIONS IN FOREST FERTILIZATION

by JAY M. HUGHES and BOYD W. POST, *Forest Resources Program, Cooperative State Research Service, USDA, Washington, D. C.*

ABSTRACT. Forest fertilization is considered in the context of: (1) the process of fertilization and forest production related to economic analyses; (2) recent ideas for economic analyses of forest fertilization; (3) additional thoughts on economic rationalization of forest fertilization; and (4) identification of research targets for forest fertilization. Available data should be considered for use in developing response surface information and fertilization simulation models that can be used to test the relative sensitivity of optional management regimes to changes in fertilizer application and economic climate.

THE GREENING of American forests through fertilizer application was probably a bit fugitive for Charles Reich as he assembled the conceptual apparatus for *The Greening of America* (1970). Nevertheless, and nurtured perhaps by the same process of economic and social evolution, fertilizer application and forest production can probably be characterized as also proceeding through three stages of "consciousness" as in Reich's view of American society.

One point in "consciousness I" might be marked by the publication of ideas on forest manuring in 1844 (*Gessell 1969*). "Consciousness II"—roughly the period between the world wars—was characterized by analyses of the roles of particular macro- and micro-elements such as Ca, P, N, and Mn in tree growth. The post-World War II period may be forest fer-

tilization's "consciousness III", in which relatively large-scale field trials of different kinds, rates, and timing of fertilizer application have been undertaken. Perhaps a "consciousness IV", which will entail use of fertilizers on an operational basis, is near at hand.

Thus far, from consciousness I through III, the major concern has been with understanding the physical and biological processes relating fertilizers to tree and forest growth and productivity. This, in economics jargon, has been analysis of the production process—the relationships of the kinds and levels of inputs or factors of production to output. To this point, however, there has been no major effort to optimize production processes—to determine the maximum-net-return combinations of fertilizers with other factors of forest production—even though

there are some papers and publications dealing wholly or in part with questions of the financial worthiness of fertilization. Two reasons for the somewhat minor emphasis on economic analysis in forest fertilization apparently are:

- The biological framework or production process needed to be described first, and this data base is still incomplete.
- Fertilization analysis does not require any new economic tools for analysis, merely the application with circumspection of tried and proven economic concepts.

FERTILIZATION IN FORESTRY PRODUCTION PROCESS

The forestry production system is the sum total of all interactions of all factors constraining as well as contributing to the output of all products of the forest. These include natural factors such as climate and soil, man-made factors such as machines, and man himself. The specific modes in which these factors interact may be called processes, such as the process of photosynthesis or the process of adjusting stand density by thinning. Forest management itself is a process that controls the combinations of factors and processes, intervening in processes where necessary, to produce desired kinds and amounts of products including pulpwood, sawlogs, game browse, and even aesthetics.

Forest fertilization can be viewed as a process that has an almost infinite variety of forms and subprocesses. Equally important are the interactions of the forest fertilization process with other processes in the forest production system. These other processes may be taken as given, or they too may be adjusted by the management process.

Thus, while certain results may be obtained by applying alternative amounts of a specific N-P-K fertilizer formulation

to a forest stand—given species, soil moisture, stand age, and density—entirely different results may be obtained from the same amounts of the N-P-K combination when any of these given factors or related processes change. Because the output from a forest production system may be more sensitive to changes in factors or processes other than forest fertilization, determination of the “best” forest-fertilization process to employ must always be made with full consideration of the other processes and factors that also affect the results of fertilizer application.

At this point we need an orderly way to look at forest fertilization for the purpose of developing useful economic guides for fertilizer use. First, we will distinguish between two general classes of forest-production factors and some of the specific factors in each class that have special relevance for forest fertilizer application. These are called, in economics jargon, “fixed” factors and “variable” factors. “Fixed” factors are those that are held at given or constant levels in the production process while output is varied as a result of changes in the levels of other factors. “Variable” factors are those whose amounts are changed to produce changes in the amount of product induced.

Fixed and Variable Factors for Forest Fertilization

Fertilization is a man-induced change in a complex ecosystem. However, it is a relatively small change in numbers of variables in the ecosystem. Thus the number of factors in the forest production system—or ecosystem—which remain fixed or unvaried as a result of man’s intervention by fertilization remains relatively very large.

Traditional analyses of forest site quality have not shown the supply of mineral nutrients to be important and have thereby tended to stress the importance of other factors of the forest environment that influence productivity.

Sites chosen for such analyses were those occupied by trees, and mineral nutrients were not obvious limits on tree growth. Furthermore, the various environmental factors determining the moisture regime tend to override the effects of mineral-element supply.

Many factors, therefore, condition the response of forests to fertilizer. Most of these factors are not manipulated or manipulatable by the forest manager. Others, like mineral nutrients, are manipulated or varied. These can be called, respectively, "fixed" and "variable" factors. For purposes of perspective we have listed some of these in table 1. The factors listed are not inclusive, nor is their classification entirely consistent. Nevertheless, it does serve to illustrate the relatively limited scope of intervention options of forest managers in the larger ecological system of the forest. This listing also suggests the need to develop analyses of forest fertilization that are more comprehensive than the throw-some-on-and-see-what-happens type.

The Generalized Functional Relationships

Some of our existing knowledge about forest response to fertilization does have utility for economic evaluation.

We seem to have considerable information about the response of forest growth to alternative rates of application of various fertilizers. A more or less classical single-variable production function results with increasing and decreasing rates of response, which can be evaluated economically to determine the optimum rate of application. Since time is customarily held constant among application-rate alternatives in most of these evaluations (growth response at some common point in time is measured for all treatments), it is only necessary to determine that rate at which the value growth response of one additional unit of fertilizer just equals the added cost of that last unit of fertilizer. At that point marginal cost and marginal revenue are equal and "profit" is maximized.

Table 1.—Environmental factors that interact with fertilizer to affect tree growth

Usually Fixed	Generally changeable	Customarily varied by managers
Climate:	Vegetation density	Stocking
Precipitation	Species	Species
Temperature	Soil:	Stand age
Humidity	Moisture	
Radiation	Nutrients	
Wind	Temperature	
Land form	Micro-organisms	
Elevation	Foliar nutrients	
Soil:	Faunal density:	
Depth	Insects	
Texture	Animals	
Organic content	* Moisture distribution:	
Root distribution	Time	
	Place	
	*Soil nutrients	

*Variation of these factors by managers may be due more to inadvertence than design.

Stratification with respect to other attributes of the forest is usually made to hold these other attributes or factors constant. As a result, it would be possible to determine the optimum rate of application for a variety of forest conditions, to the extent that these conditions fit the attributes held constant. Thus we find that response to alternative rates of application varies directly with respect to such fixed factors as basal area, age, site index, and soil moisture. That is, the response curve for a basal area of 250 square feet per acre of Douglas-fir is higher than that for 190 square feet. Likewise, as site index increases, so does the response level. Rates of response, of course, may vary among levels of these fixed factors; and this will mean that when the level of the fixed factor changes, the optimum rate of application will change.

Because of the obviously limited value of single-variable response data, response surfaces representing the interactions of two or more variables are needed. We will simply note here that there is apparently relatively little multivariable response information for forest fertilization. In addition to new studies designed to obtain such data, we would urge that the results of existing studies be examined to determine their suitability for estimating multivariable responses to fertilization.

ECONOMIC RATIONALIZATION OF FOREST FERTILIZATION

We recently inventoried current USDA-funded and state agricultural experiment station research reported to CRIS (the Current Research Information System administered by the USDA Cooperative State Research Service) and found some 56 current projects in all forest regions of the United States dealing wholly or in part with forest fertilization. These included U. S. Forest Service research projects. Not one of the project

reports in this inventory mentioned economics analysis as part of the project. Even if we concede the incomplete information base of CRIS reports, it would appear that solid and sustained economics research in forest fertilization has received short shrift, at least by the public forestry research community.

Nevertheless, there are allusions to the economic benefits of forest fertilization in many publications and papers on the subject, and a few articles dealing mainly with its economic aspects. Four of these are discussed below.

A Generalized Financial Model

One criterion that may be used to answer the question, "Does fertilization pay?", is present net worth. This has the general form of:

$$Pnw = \frac{R^t}{(1+i)^t} - \frac{C(1+i)^{t-n}}{(1+i)^t}$$

in which

Pnw = present net worth.

R = revenue

C = cost

t = time of receipt of revenue or harvest

n = time period from present to investment in treatment or occurrence of fertilization cost.

i = required rate of return.

Without consideration of other factors, if $Pnw \geq 0$, it "pays" to fertilize. That is, you will have at least earned or bettered the required rate of return on the investment in or cost of fertilization. At the end of the investment period, t, you will have recovered all investment costs, C, plus an increment equivalent to at least what C would have earned at i invested elsewhere at the same period of time.

Two observations stem from the logic of this equation. First, all other things remaining constant, the higher the required rate of return, the smaller the present net worth. Second, all other

things remaining constant, the larger the size of n , the lower the costs and the higher the present net worth. That is, the closer to the time of harvest when the fertilization investment is made, the lower the investment costs. These two observations, coupled with other aspects of the fertilization system, are frequently found in the literature; and their basic relevance is tied to the logic of this economic criterion.

This criterion can be applied to any number of management options, and that option that yields the largest present net worth may be chosen as optimum or the "best". Thus, options which use different kinds, levels, and times of fertilizer applications may be compared with this criterion. In addition, other treatment costs and returns may be added in similar form to the criterion for comparing any number of management options, which include fertilizers as only one subpart. And regularly repeated applications can be evaluated (for example, application of fertilizer 10 years before rotation harvest for each rotation in the future) with a minor modification of the basic equation.

The main point of all this is that the financial model for evaluating fertilizer application, by itself or as part of a larger management system option, is already well known. The main requirement is simply an orderly time-specific accounting for the various cost and return elements in the criterion and some capability for predicting or forecasting the cost-and-return effects of alternative management system options.

Haley (1967) has developed a somewhat elaborated version of this general approach and has shown some standard options for discounting costs and revenues given periodicity of fertilizer applications. He also pointed out some additional implications of using compound interest—for example, doubling the frequency of application of fertilizer within a given time period will more than double the financial cost over that period.

The Shadow of Uncertainty

The rational precision and neatness of present net worth calculation has tremendous appeal. Unfortunately—and it is always thus—real-world data do not match the precision of the model in which they are used. This is not to deny the validity of the method, but only to point out the obvious: we do not know with certainty the various attributes of the future that our model requires. We do not know what prices will be; we do not know what costs will be; we do not know the interest rate that should be used from time period to time period; and, most important perhaps, we really do not yet know very precisely the response levels of forests to fertilizer.

We are, in a word, uncertain about the reliability of the data we are still forced to use in the model. More important, we are uncertain about the degree to which we may err in our management prescription, which will stem from our precise calculations; and it is this kind of uncertainty that has the most immediate impact upon decisions to incorporate fertilization in management practices.

Schweitzer¹ has summarized this concern for uncertainty in forestry decision-making with special emphasis on forest fertilization. He notes that we always have imperfect information, but we make decisions anyway. Two general classes of uncertainty mitigation are identified. One of these can be labeled "institutional"; it includes elements that reduce the value or importance of risk and uncertainty associated with relatively minor parts, such as a fertilization regime, of a total system or enterprise. Some managers may include fertilization

¹Schweitzer, Dennis L. 1971. Forest fertilization in the Pacific Northwest: a case study in timber production under uncertainty, to be published in Proceedings of the Forest Economics Sub-Group Workshop on Uncertainty in Forestry Investment Decisions Regarding Timber Growing; International Union of Forestry Research Organizations, Gainesville, Fla., 21 March 1971.

as a production option simply to accumulate a level of experience comparable to that of competing managers. In some cases, a fertilization practice may be implemented simply to produce higher and more timely yields for overall production goals and may not be viewed as a profit-center activity by itself.

A second class of uncertainty mitigation involves such strategies as using a conservative bias in forecasting the yield impact of a fertilization practice; adding a safety margin for costs; reducing expected profit margins by some arbitrary factor; and inflating the discount rate to account for risk. Schweitzer pointed out that environmental concerns are now providing additional rationale for safety-margin strategies. Undesirable nutrient impact on water quality is a principal concern in this regard and certain waterside areas are now excluded from fertilizer application.

In summary, a number of uncertainty issues can be raised in the context of forest fertilization. The most important general class seems to be that of forecasting yield effects of fertilization. Another important class is application costs, especially since effective application systems are still in the developmental stages. Finally, we need to identify those management options that are most sensitive to uncertainty strategies regarding fertilizer application. If what we propose to do in our total management system would change little even if our fertilizer subsystem changed greatly or gave wildly varying results, we need not be too concerned about obtaining more certain or more precise information about fertilizer effects.

The Allowable Cut Effect

Schweitzer alluded to a somewhat controversial notion in forest regulation called the "allowable cut effect". The reasoning is simple: if a practice such as fertilization is applied today, and it is es-

timated to increase allowable cutting levels in the future, present cutting levels may be increased accordingly. If, for example, a technical rotation (one that will yield sawtimber-size trees in a given period of time) is shortened by the fertilization practice, and area regulation is employed, the amount of area cut today can be increased by the amount of increase in area devolving from the calculation for the shorter rotation periods.

Brantseg (1966) applied this notion specifically to fertilizer application. On the basis of logic and some limited calculations, Brantseg suggested that the growth increment attributable to fertilization can be harvested from existing harvestable trees elsewhere in the allowable-cut unit as soon as the growth increment is discernible, rather than waiting for today's fertilized trees to reach harvest age or size.

The beneficence of this phenomenon is apparent. The financial yield from increased present harvests can help offset the present costs of fertilization. Ultimately, however, the increased annual yields must cover the time costs associated with the present net investment in fertilization. In addition, and most important, there must be current *harvestable* material in extra amounts equivalent to the increase in current growth. This, in turn, begins to suggest the special care required to evaluate the allowable-cut effect as a means of capturing future benefits in the present.

Generally, the allowable-cut effect appears most relevant for the conversion period in forests with an overabundance of mature or near mature timber. It has no special relevance in forests with an understocking or immature-age-class bias. And in any event, it may be regarded as only a special case in forest practice evaluation. If all annual costs and all annual returns based on all forecast annual yields from a given forest property are accounted for within a fully regulated sustained-yield forest model,

the so-called allowable-cut effect should be built into the annual cutting level prescription automatically.

One final note of caution. Intensive forest-management practices may not always lead to shorter rotations. It is easy to demonstrate that thinning may lead to longer biological rotations, because thinning in some stands will increase average annual growth and yield, thus pushing the culmination of mean annual increment farther into the future. Financial rotations may be similarly affected. Fertilization may in some cases increase periodic annual value increment more than it increases the annual cost of forest management and production. In such a case it would pay to move the rotation or final harvest farther into the future to that point where the added value yield just equals the added cost of waiting and treatment.

The Economist's Complaint

In 1967, at the Forest Fertilization Symposium at Gainesville, Fla., Stoltzberg and Phares (1968) concluded with what may be termed "the economist's complaint": perhaps more economics would be applied to fertilization *if only the data were adequate!* Adequacy in this instance means unbiased and efficient estimates of the response surfaces for various levels and combinations of fertilizers. These authors and Clutter (1968), in a paper at the same symposium, argued for a shift in experimental design to rotatable composite designs that economize on treatment combination and emphasize response surface analyses.

Nevertheless, we believe there is an abundance of data already available that can lend itself to some useful economics analysis. Some of the general single-variable functions delineated earlier may be evaluated in an economics context to provide some assistance to forest managers in deciding on worthwhile fertilizer treatments. What seems to be required is not

only more data of a more adequate form, but more sifting and sorting through existing data to utilize it in decision-making.

SOME GENERAL GUIDES

The guides suggested below are mainly logical and procedural in nature. Instead of detailing instances in which fertilization "pays", we offer some suggestions for approaches to answering this question, and we note some circumstances that seem to embody the best chances for profitable fertilizer applications.

The Management Decision Framework

Forest management in North America is still an immature art and relatively unsophisticated. Much management is still merely a matter of scheduling the harvest of existing timber. Even where new and man-cultivated forests have been developed, natural site productivity is utilized. Fertilization can be considered a relatively advanced form of site-productivity modification.

Generally, in our unsophisticated forest-management framework, only two variables (inputs) are controlled by the manager: (1) time and (2) stocking. Most textbook forest management and certainly much current management planning is built around the manipulation of these two variables, either individually but more frequently in combination.

The time variable has several forms: (1) time for regeneration of harvested areas; (2) time between cultural treatments, including thinning and perhaps fertilizer application; (3) time period of the cutting cycle in mixed-age management; and (4) time or age of harvest.

The stocking variable likewise has several forms, including initial stocking levels and after-thinning stocking; and these are measured in several ways including basal area, stems per acre, and

volume in trees of designated size or age classes.

We would argue that most current management decisions for forest production can be boiled down to making choices between alternative combinations of some time and stocking attributes of the forest. Other variables of the forest production system, though requiring some decisions prior to this one, will usually be taken as given. Thus, for a given combination of site (and all of its inherent variables) and species, and for a selected set of production systems (logging or other treatment system with its associated costs), the best combination of time of treatment (or intervals between treatments) and the number of trees or stocking levels to which the treatment applies will be sought.

Like the response surface generated from composite rotatable statistical designs, showing the yield interactions of N and P in a fertilizer formulation, response surfaces in timber yields for time and stocking combinations can be generated. Every yield point on the response surface can be evaluated by using present net worth analysis as discussed earlier. That interaction or combination of time and stocking yielding the greatest present net worth would be chosen to guide the forest manager's decisions.

If the foregoing management-decision framework is an accurate portrayal of the manager's concern, when, how, and where are forest-fertilization decisions made? There are two basic ways in which fertilization decisions can be articulated with the time-stocking decision model. One is to take as given a specific fertilizer formulation, rate, and time of application. Given the specific fertilizer regime, the manager's decision is to choose the best combination of time and stocking.

The second basic way to articulate fertilization decisions with the time-stocking decision model is to incorporate some elements of the fertilization regime directly into the model, defining time and

stocking attributes in fertilizer-regime terms. For example, a fixed formulation of N-P-K fertilizer may be assumed. Time and rate of application must still be determined to complete the fertilization-regime structure for the given site and species. Instead of using alternative rotation lengths as the time parameter, alternative times of application or lengths of time between applications may be used.

Stocking could be held constant, rate varying with application time; or rate could be expressed in stocking terms and stocking and rate varied with time of application. An expression of this latter possibility might be pounds of the given fertilizer formulation per 100 trees or 100 cubic feet of stocking per acre.

Although the exact functional relationships implied by the above suggestions are not clear, the time-stocking model is suggestive of the kind of response surface information that lends itself readily to the forest-management decision system. Perhaps this will be useful in the design of subsequent analyses of the effect of fertilizer on forest growth and yield.

Priority Possibilities for Fertilizer Payoff

We have not made a systematic—or economic—appraisal of the various opportunities or circumstances in which high payoffs are most likely from forest fertilization. Nevertheless, there seem to be a few generalizations to guide the direction in which we might seek such high payoff opportunities.

First, good sites will likely offer the best opportunities to take advantage of the benefits offered by fertilization. This will be related primarily to favorable soil-moisture conditions. This in turn suggests that irrigation and fertilization practices together should be evaluated because they are strongly supplementary to each other.

Second, high-value species seem likely to offer better payoff opportunities than

low-value species. This follows from the realization that application costs are not as responsive to species variation as are value yields. Thus high-value, high-value-response species such as walnut and oak would probably rate higher in fertilizer treatment priority than red pine or aspen.

Third, minimization of fertilizer investment time has financial payoff, which suggests two strategies. One is to apply the fertilizer late in the rotation to minimize investment costs, but not so late as to lose the yield effect of the treatment. Another strategy that may be worthwhile in the future would be to couple fertilization with very short agronomic production cycles where feasible. Such possibilities may exist in future development of very short aspen rotations, and perhaps in the so-called "sycamore silage" type of operation. Both types of development emphasize fiber yield, with little regard for the macrostructure in which fiber yield is packaged.

Finally, application systems and their costs need to be considered in identifying general high-priority possibilities for fertilizer payoff. Getting the fertilizer to the tree in the right amount at the right time without creating secondary problems such as stimulating growth of unwanted vegetation and incurring extra costs such as those of storage during inclement weather is still a major problem. The application system may in some instances be a more important consideration than the ultimate yield impact because of costs or lack of effective controlled distribution of yield impact.

SUMMARY AND CONCLUSIONS

We have not presented the results of original or new research in forest fertilization. Nor have we presented a complete display of economics research in forest fertilization. We have tried instead to present an outside point of view, relat-

ing economics concepts to some of the more well-known aspects of forest fertilization. We have also tried to place this discussion in a management-decision context.

We concluded early in our review that the tools for economic analysis of forest fertilization already exist. The needs are therefore those of application, not development. Furthermore, major issues of application are those common to other fields. One of these is simply the need to account for all the yields and costs of alternative fertilization programs in a time-specific manner to apply the tools of financial analysis. Another is the need to measure the incremental effects of the full range of fertilizer-application options so that optimum treatments can be determined. This in turn embodies previous recommendations by others (*Stoltzenberg and Phares 1968*) to design fertilizer experiments that will generate response surfaces rather than simple tests of significant differences among a limited range of treatments.

The time and stocking management context that we have suggested is admittedly simple. It is difficult to imagine any management system with only two variables. In this regard we would like to stress that we are not proposing a two-variable management system; but we do believe that these two variables are the major manipulatable variables in forest management and that they do provide a useful core concept around which we may organize what we need to know about forest fertilization.

Finally, we argue that fertilization evaluation out of context seems a somewhat fruitless endeavor. Care needs to be taken to evaluate all factors associated with forest yield where fertilization might also be considered. Other biological factors may overshadow even the most optimistic forecast of fertilizer effects; and the economic environment may militate against the realization of any worthwhile gains. Perhaps the time is at hand

when accumulated knowledge will lend itself to fertilizer-simulation models that can be used to test the relative sensitiv-

ity of optional management regimes to changes in fertilizer application and economic climate.

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FERTILIZER METHODS AND APPLICATIONS TO FORESTRY PRACTICE

by J. D. BEATON, *Director, Agricultural Research,
The Sulphur Institute, Washington, D. C.*

ABSTRACT. Although N and P are the nutrients that most frequently increase tree growth and vigor in forest stands of eastern North America, other elements, including K, S, Ca, and Mg, are also beneficial. Most fertilizer products suitable for use in forestry exert considerable influence on the chemical and physical properties of forest soils, mainly through temporary and permanent changes in soil pH. Solubilization of organic matter, release of plant nutrients, and movement of nutrient cations are all affected by fertilizer-induced alterations in soil reaction. The best opportunity for placing fertilizers is during site preparation for new stands. Aerial applications are often the only practical method of topdressing extensive areas of established stands.

TRÉES ARE LIVING organisms, and for their maximum development a number of environmental conditions must be favorable. Soil fertility is one of the important factors. If the plant-nutrient status of a soil is suboptimal when the other growth factors are sufficient or nearly so, poor tree growth will result. Forest trees receiving proper nutrition are more likely to be capable of withstanding stress conditions such as drought, disease, insects, etc., just like agricultural crops. There is evidence that P fertilization tends to compensate for soil conditions restricting development of tree roots.

Forest soils are usually low in fertility because soils of better nutrient status and productivity are customarily used for agricultural purposes. Removal of plant nutrients from these rather infertile soils is accelerating through the adoption of intensive management practices, resulting in greater tree vigor and productivity. More complete utilization of the tree crop is also contributing to greater withdrawal of plant nutrients from forest soils. In some areas, unformed public opinion has recently forced foresters to abandon their long-standing practice of broadcast-burning slash, which aided in the recycling of plant nutrients, and to

turn to burning large accumulations of forest wastes at a few specified locations.

Research on the benefits of forest fertilization is relatively new in North America. Fertilizers were included in a few experiments in forests of the South about 40 years ago, and serious research was not started there until some 25 years later (*Bengtson 1968*). Tree-nutrition research has been under way for about 30 years in the Lake States and the Northeast (*White 1968*). Research work on the nutrient needs of forest trees in the Pacific Northwest started around 1950 (*Gessel 1968*).

Commercial fertilization of forests in North America is not widespread (*Beaton and Tisdale 1969*), and most of the fertilized forest land in the United States received treatment within the past 5 years (*Bengtson 1971*). Operational-scale forest fertilization began on Vancouver Island, British Columbia in 1963 (*Beaton and MacRae 1967; MacRae and Beaton 1968*).

The purpose of this paper is to consider the commonly accepted principles of fertilization and their applications to forestry practice.

FERTILIZER PRINCIPLES

The five basic principles for sound use of fertilizers in forestry practice are:

- Identify the nutrients currently limiting growth and those present in marginal amounts.
- Use the most effective fertilizer materials for a given set of conditions.
- Apply proper rates of the required nutrients to avoid excesses and imbalances.
- Fertilize so that nutrients are available when needed most.
- Place fertilizers so that the nutrients being supplied are positionally available.

IDENTIFICATION OF NUTRIENTS

LIMITING GROWTH

Soil Testing

Soil testing, either alone or in conjunction with plant analysis, is the most commonly used tool for diagnosing the need for fertilization of agricultural crops. Before either soil testing or plant analysis can be used to formulate fertilizer programs for crop production, background information relating soil-test values and nutrient concentrations in plant tissue to growth and yield must be available. Agriculturists have been involved for many years in making fertilizer recommendations and have collected much of this type of data. Their task of relating growth to plant tissue and soil-test values is considerably easier than that of the forester because they are often working with annual crops.

Use of soil tests for diagnosing the need for fertilization of forest trees has had only limited success. Readily available soluble nutrients are probably less important for development of perennial plants such as trees than they are to growth of short-lived annual crops (*Leaf 1968*). Also, the extractants used to measure nutrients available to annual field crops may not satisfactorily estimate the "available-to-trees" fraction of nutrients in soil. However, the usefulness of soil tests developed for agronomic crops should not be discounted entirely since Pritchett (1968) reported that levels of approximately 2 p.p.m. or less of NH_4OAc -extractable P in surface (0 to 20 cm.) soils were insufficient for good growth of slash pine. Increased growth of loblolly and slash pine is expected from fertilizer P additions in the South Carolina Coastal Plain when available soil P is less than 11 kg./ha. (*Wiley et al. 1970*).

Measurement of total and potentially available plant nutrients is probably a more realistic approach to predicting the

need for fertilizers. Total N concentrations of less than 0.1 percent in the surface 15 cm. of glaciated soils in northwestern Washington generally indicated inadequate levels of this nutrient for Douglas-fir (*Gessel 1968*). Soils deficient in K for red pine can be distinguished from nondeficient soils by means of a test for the potentially available portion of this nutrient in soil (*Leaf 1968*).

Tissue Testing

Tissue analysis promises to be a useful tool for detecting inadequate levels of plant nutrients in established forest stands. Several comprehensive reviews of plant analysis guidelines for assessing the nutrient status of forest trees have been published recently (*Bengtson et al. 1968; Leaf, in press*).

A few examples of important nutrient status levels follow. Growth response of loblolly pine to N fertilization is expected when the foliar concentration of this nutrient is less than 1.16 percent (*Wells 1968*). Levels below 1.0 percent total N in current year's Douglas-fir foliage sampled in September or October are considered indicative of N deficiency (*Gessel 1968*). Growth of 5- to 8-year-old slash pine on Flatwoods soils can be increased by P fertilization when the concentration of this nutrient in the needles is between 0.09 and 0.10 percent (*Pritchett 1968*). Responses of loblolly pine in the South Carolina Coastal Plain to P fertilization were expected when foliage contained less than 0.11 percent P (*Wiley et al. 1970*). Benefits from K fertilization of red pine are expected when the concentration of this nutrient in current year's near-terminal foliage is between 0.3 and 0.4 percent in October (*Leaf 1968*).

Fertilizer Trials

In the absence of soil tests and tissue analyses that are well correlated with tree growth or forest productivity, fertilizer trials can be conducted to assess the

nutrient status of forest soils. Many such trials have been conducted in North America, and the results to date indicate that N and P are the nutrients that most frequently increase tree growth and vigor.

In addition to N and P, dressings of other nutrients—including K, S, Ca, and Mg—have been beneficial for stands of various forest species in eastern North America (table 1). There is evidence that combinations of two or more essential nutrients may result in substantially larger increases than applications of a single nutrient (*Swan 1969a*). Swan (1969b) reported that in his 10 years of field experience in eastern Canada, N only treatments were always less effective than N plus K or P.

The need for more than one plant nutrient or "balanced fertility" is not a new concept. Most agronomists are constantly faced with prescribing fertilizer programs involving two or more nutrients. Heavy rates of N, P, or K fertilization often lead to deficiencies of nutrients such as S, Mg, Ca, and the micronutrients. The recent findings of van Lear and Smith (1972) that Cu, Mn, and Zn supplements increased the response of slash pine seedlings to applications of N and P certainly indicate that nutrient balance should not be overlooked in forest fertilization.

USE OF MOST EFFECTIVE FERTILIZER MATERIALS

Changes in Soil pH

Although fertilizer properties may be just as important as those of the forest floor and underlying mineral soil, little attention has been given to the selection and use of materials that will produce the most favorable nutritive conditions for tree growth. Most fertilizer materials suitable for use in forestry will exert considerable influence on the chemical and physical properties of forest soils through

Table 1.—Some examples of forest response to fertilization in Eastern North America

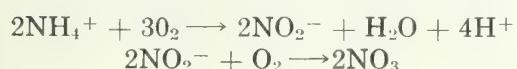
Location	Species and age of stand	Nutrient resulting in growth response	References
CONIFEROUS SPECIES			
Northern New York State (Adirondack Region)	Young plantations of red pine, white Pine, Norway spruce, and white spruce	K	Heiberg & White 1951
Northern New York State (Adirondack Region)	Young plantations of red pine	Mg	Stone 1953
Quebec	Plantations of white spruce	K,Mg	Lafond 1958
Quebec	20-year-old plantation of red pine	K,Mg	Gagnon 1965
Maine	White pine plantation	K,NPK	Stratton et al. 1968
Quebec	60-year-old jack pine stand	K,NK	Swan 1969a.
Quebec	White spruce stands	N,NK	Swan 1969a
Ontario	85 year-old black spruce stand	P	Swan 1969a
New Brunswick	40-90-year-old black spruce stands	NP	McFarlane & Krause 1972
Atlantic Coastal Plain	Young plantations of loblolly and slash pine	P	Bengtson 1968; Brendemuehl 1968; Pritchett & Smith 1968; Wiley et al. 1970
Borrow pits in South Carolina	2-year-old slash and loblolly pine seedlings	N,NS	McGregor & Goebel 1968
Atlantic Coastal Plain	Plantations of southern pines following crown closure, approximately 15-20 years old	N,NP	Bengtson 1968; Pritchett & Smith 1968; Pritchett & Hanna 1969
Coastal Plain in Florida	9-18-year-old slash pine plantations	N,NS	Pritchett personal communication 1972
Tennessee Valley	20-75-year-old southern pines	N,NP	Farmer, Bengtson & Curlin, 1970
HARDWOOD SPECIES			
Michigan	19-year-old tulip-poplar plantation	N,K,NK	White 1968
Michigan	25-year-old black walnut plantation	NPK	White 1969
Ohio	30-year-old yellow-poplar plantation	NPK	Vimmerstedt & Osmond 1968
Massachusetts	Sugar maple trees	N	Mader et al. 1969
Pennsylvania	50-year upland oak (white and scarlet oak)	N,Ca,NCa	Ward & Bowersox 1970
Tennessee (3 locations)	Merchantable upland hardwood stands (northern red oak, white oak, chestnut oak, southern red oak, yellow-poplar, black cherry, hickory, dogwood)	N,NP	Jones & Curlin 1968
North Carolina	Merchantable upland hardwood stands	N,NP	Jones & Curlin 1968
Tennessee Valley	Second-year growth response of cottonwood clones	N	Jones & Curlin 1968
Louisiana	20-year-old stand of sweetgum, water oak and willow oak	N,NPK	Broadfoot & Ike 1968
Georgia	One-year-old yellow-poplar seedlings	N,NP	Broadfoot & Ike 1968
Georgia	One-year-old sycamore seedlings	N	Broadfoot & Ike 1968
Tennessee Valley	20-75-year-old mixed stands of yellow-poplar, red and white oaks, and hickories	N,NP	Farmer et al. 1970

alteration of soil pH. Changes in soil reaction following the introduction of fertilizers can be either temporary or permanent.

The saturated solutions that diffuse from dissolving fertilizer granules have pH's ranging from very acid to slightly alkaline. These saturated solutions will temporarily alter soil pH and affect soil chemical and physical properties. The composition and pH of saturated solutions of several important P carriers is shown in table 2.

During the hydrolysis of urea or urea-containing fertilizers, transitory alkaline solutions are formed which have both direct and indirect effects on the forest floor, as well as on mineral soil (*Beaton et al. 1969; Bengtson 1970*).

Most ammonium-containing or forming fertilizers will permanently lower the pH of agricultural soils. Development of acidity is the result of nitrification or oxidation of NH₄-N to NO₃-N as illustrated below (*Tisdale and Nelson 1966*):



Soil reaction has a pronounced effect on nitrification, the optimum pH being close to 8.5 (*Tisdale and Nelson 1966*). Nitrification can occur, however, over a range of reaction between pH 5.5 to about 10. It is known to take place in some agricultural soils at pH values as low as 4.5 and 3.8, but in forest soils nitrification may practically cease at pH's

below 5.0. Nitrification is usually considered to be relatively minor in forest soils. Consequently, the acidifying effect of nitrification is probably not as complete in forest soil environments as it is in agricultural soils because the former are generally more acid to begin with.

Drastic reductions in soil pH are not usually desirable for several reasons. First, loss of nutrient cations by leaching is enhanced by acidic soil conditions. Second, when soil pH decreases below 5.5 there is a very great increase in concentration of Al in soil solution. Soluble Mn becomes high at pH's below 5. High levels of these two elements are toxic to plants. Third, available P in soil can be reduced markedly through the formation of insoluble iron and aluminum phosphates.

Preliminary investigations by Dr. S. P. Gessel, Dr. I. Morrison and Dr. T. N. Stoate at the University of Washington suggest that Mn toxicity may be the factor limiting growth of Douglas-fir in one area of northwestern Washington (*Anonymous 1971*). Apparently the presence of excessive amounts of Mn has induced an Fe deficiency. In trials established by these investigators, Douglas-fir has shown a better response to Fe plus N than to N alone.

Phosphorus fertilizers, with the exception of phosphoric acid and the ammonium phosphates, do not generally have any marked effect on soil pH. The common K carriers similarly do not alter soil reaction.

Table 2.—Composition of saturated solutions of phosphorus fertilizers

Fertilizer	Symbol	Composition of saturated solution at 25°C		
		pH	P	Cation
Ca(H ₂ PO ₄) ₂ ·H ₂ O	MCP	1.48	3.98	1.44
NH ₄ H ₂ PO ₄	MAP	3.47	2.87	2.87
KH ₂ PO ₄	MKP	3.99	1.69	1.69
(NH ₄) ₂ HPO ₄	DAP	7.98	3.82	7.64
K ₂ HPO ₄	DKP	10.1	6.10	12.2

Source: Lindsay, Frazier, & Stephenson 1962.

Table 3.—Equivalent acidity and basicity of common fertilizer materials

Fertilizer	Percent N	Equivalent acidity or basicity (B)—	
		Per kg. of N	Per 100 kg. of material
<i>kg of pure lime</i>			
Ammonium sulphate	21	5.35	110
Ammonium nitrate	33.5	1.80	62
Urea	45-46	1.80	84
Urea-ammonium nitrate solution	32	1.80	57
Calcium nitrate	15	1.35(B)	20(B)
Potassium nitrate	13	2.00(B)	23(B)
Monoammonium phosphate	11	5.30	58
Diammonium phosphate	18	5.30	96

Source: Tisdale & Nelson 1966.

Equivalent acidity or basicity of several of the most widely used fertilizer materials is shown in table 3. Ammonium sulphate will result in considerably more acidity than either ammonium nitrate or urea. Ammonium phosphate products also have considerable potential for acidifying soil.

Salt Index

All fertilizers increase the salt concentration of the soil solution. Salt index is a measure of this effect. It is defined as the percentage rise of the osmotic pressure brought about by a fertilizer in comparison with the effect of the same quantity in weight of sodium nitrate (*Baule and Fricker 1970; Tisdale and Nelson 1966*).

Some fertilizer salts, when present in low concentration, appear to cause injury to plants by interfering with metabolic processes, while others do not seem to be harmful until osmotic pressure of the soil solution is raised above that of cell sap. Table 4 shows that there is considerable difference in the salt index of the various products available for forest fertilization. Materials with the lowest index should be used in situations where salt injury is or could be a problem—forest nurseries, planting holes, etc.

Chloride

The Cl component of fertilizer materials may result in injury to conifer seedlings (*Baule and Fricker 1970*), espe-

Table 4.—Salt index of common fertilizer materials

Fertilizer	Percent N, P or K	Salt index per unit of plant nutrient
Ammonium sulphate	21	3.25
Ammonium nitrate	35	2.99
Urea	46	1.62
Ordinary superphosphate	8.7	.39
Concentrated superphosphate	20.9	.21
Monoammonium phosphate	22.2	.49
Diammonium phosphate	23.6	.64
Potassium chloride	50.0	1.94
Potassium nitrate	38.3	1.58
Potassium sulphate	45.0	.85
Potassium magnesium sulphate	18.3	1.97

Source: Tisdale & Nelson 1966.

cially to sensitive species such as Norway spruce. It is not clearly understood if the detrimental effect is due to higher osmotic pressures in the soil solution or toxicity of the ion itself. Chloride-containing materials can probably be used without reservation when applied at reasonable rates to older stands, particularly broad-leaved trees. Other factors that have a bearing on the suitability of products containing Cl are frequency, time, and rate of application; precipitation patterns; and ease with which the ion moves out of the root zone.

Free Ammonia

Several of the N and N-P fertilizers when applied to soil may form or release NH₃. Free ammonia is toxic and can move freely through cell walls, whereas NH₄⁺ cannot. Because of this factor the effectiveness of urea, diammonium phosphate, ammonium carbonate and ammonium hydroxide might be less under certain conditions than that of monoammonium phosphate, ammonium sulphate, and ammonium nitrate.

Selection of a Nitrogen Fertilizer

A variety of fertilizers provide NO₃-N, and many other materials supply or form NH₄-N in soil. Three of the many factors that may influence the choice of a N fertilizer are: preference, if any, of tree species for NH₄⁺ or NO₃⁻; potential for acidifying forest soil and increasing the rate of release of nutrient cations from the forest floor; and prospective leaching losses of NO₃-N.

Growth of mycorrhizae, which are often essential to tree growth, is suppressed more by NO₃⁻ than NH₄⁺ (*Pritchett and Smith 1969*). Ammonium and urea compounds are generally the preferred N forms for forest species (*Pritchett and Smith 1969*). It is also suspected that NO₃-N and high levels of inorganic N may increase the sus-

ceptibility of forest species to certain plant pathogens.

Other important factors that will affect the selection of N sources are cost per unit of N; commercial availability of product; and costs associated with handling, storage, and application. The rather wide acceptance of urea for forest fertilization in North America, especially in operational-scale programs, is probably due mainly to the above reasons. The advantages in applying this most concentrated solid N source are obvious.

A number of investigators (*Bengtson 1970; Volk 1970; and Watkins et al. 1972*) have been concerned about gaseous losses of NH₃ during the hydrolysis of urea in forest floor environments. These losses, if significant, would tend to detract from urea's desirable characteristics and advantages. Substantial losses of NH₃ from urea were found in laboratory studies conducted by Watkins et al. (1972) in the Pacific Northwest. Variables such as air movement, temperature, and pH of mineral soils all had considerable influence upon the ammonia losses. Gaseous losses of NH₃ from prilled urea applied to several slash pine sites in Florida were less than 10 percent of the total N applied (*Volk 1970*).

There is no doubt that some volatilization of NH₃ takes place following the application of urea to forest soils but the losses are expected to be rather minor, especially if the fertilizer is applied during periods of mild temperatures plus significant precipitation.

Applications of urea have pronounced effects upon the forest floor. The alkaline solution that forms upon the hydrolysis of urea will solubilize large amounts of organic matter and plant nutrients such as P (*Beaton et al. 1969*). Cations such as K, Na, Ca, and Mg are displaced from forest humus by this solution; and Fe, Mn, Cu, and Zn are transported into the soil profile in association with the dispersed organic matter (*Cole and Gessel 1965*). Although these solutions persist

for only rather short periods of time, they are apparently capable of breaking down otherwise resistant humus complexes. These solubilized organic complexes may also undergo further breakdown by soil microorganisms. Thus applications of urea will aid in the recycling of plant nutrients stored in forest humus.

There is a possibility that substantial quantities of urea are immobilized in forest humus (*Ogner 1972*). It is not known if this immobilization reduces the effectiveness of urea dressings. If the resulting humus complexes are reasonably reactive, they may act similarly to controlled-release N sources. On the other hand, stable complexes may release insufficient amounts of N.

Supplies of ammonium sulphate are very plentiful in North America, and this product may find greater use in forest fertilization, especially if the cost per unit of N is low enough to compensate for higher transportation and handling costs. In addition, the S component may have a favorable effect upon tree growth (*Beaton 1966; McGregor and Goebel 1968; Pritchett, personal communication 1972; Turner 1968; and Youngberg and Dyrness 1965*).

Before using large amounts of ammonium sulphate on forest soils, it is prudent to recall its high residual acidity in soil and the attendant leaching of nutrient cations (*Beaton et al. 1969; Cole and Gessel 1965*). However, when soil base status is adequate, greater release of cations and acidification should not be a serious problem. Greater movement of cations will probably not adversely affect soil fertility when tree-root systems are sufficiently well developed to intercept and absorb most, if not all, nutrients in solution.

Homogeneous combinations of urea-ammonium sulphate have considerable promise as N-S fertilizers because their physical properties are superior to those of urea alone (*Beaton and Fox 1971*).

Furthermore, the possibility of sizable losses of NH₃ during hydrolysis of urea should be greatly lessened by the dilution effect of ammonium sulphate. The ratio of N to S in these products is more nearly in keeping with plant requirements than it is in ammonium sulphate. Soil acidity developed from urea-ammonium sulphate products should be less than with ammonium sulphate only.

Ammonium nitrate is a very popular source of N for agricultural crops, but it has not been generally accepted for forest fertilization. Presumably, factors such as the possible leaching of NO₃-N, somewhat higher costs for the N as well as for handling and application, and the potential of this material for lowering the ignition point of combustible materials have all contributed to a lack of interest in its use. It should be noted, however, that beginning in 1968 there was a marked shift in the source of N applied to Swedish forests (*Holmen 1969*). Urea was used almost exclusively in the years 1964-67 while in 1968 urea accounted for only 69 percent of the total N applied and ammonium nitrate represented the remaining 31 percent.

Pritchett and Smith (1969) indicated that controlled-release N materials such as urea-formaldehyde and sulphur- or paraffin-coated urea have promise in the fertilization of young slash pine plantations. Slow-release products probably have their greatest potential for treatment of young stands before crown closure and before root systems are adequately developed to intercept most of the dissolved plant nutrients.

An experimental product prepared by coating granular urea with a slurry composed of 72 percent elemental S, 18 percent bentonite, and 10 percent ammonium sulphate by weight appeared to offer advantages over ammonium nitrate and urea-only treatments in Douglas-fir trials on Vancouver Island, British Columbia (*unpublished data, 1970, Pacific Logging Company Limited and Cominco Ltd.*).

The final analysis of this material was 39 percent N and 11 percent S. Its greater effectiveness is believed to be due mainly to the coating that slightly delays and prolongs the dissolution of urea.

Selection of a Phosphorus Fertilizer

A number of P carriers are available for use in forestry. Ordinary and concentrated superphosphate are the most extensively used sources of P. Other promising water-soluble P fertilizers are mono- and diammonium phosphate and ammonium polyphosphate. The ammonium present in ortho- and polyphosphates will provide supplemental N and may also have the favorable effect of enhancing P absorption. Polyphosphate products offer some degree of chelation, which might be beneficial in situations of marginal micronutrient nutrition.

All of these water-soluble P sources will react with various soil constituents—including Fe, Mn, and Al—to form less soluble reaction products. Availability of P is decreased when this occurs, especially if the reaction products are coarsely crystalline. Additions of soluble sources will immobilize excess Al and Mn in some acid soils and reduce the mobility of these elements within plants. The concentrated P solution, which diffuses from dissolving granules of ammonium ortho- and polyphosphate, dissolves soil organic matter and releases plant nutrients (*Bengtson 1970*). Diammonium phosphate products are likely to have the most pronounced effect, due to the high

pH of their saturated solution. Table 5 shows the composition of various saturated fertilizer solutions following their reactions in a podzol soil.

Water-soluble P carriers are likely to produce the greatest benefit when a prompt response is desired, as in forest nurseries, for plantings on severely P-deficient soils, and on older stands suffering from a shortage of this nutrient. Their effectiveness will probably be greatest on poorly drained organic or coarse-textured soils low in soluble Fe and Al and on near-neutral or alkaline soils.

Slowly available or sparingly soluble P sources—including colloidal phosphate, rock phosphate, and basic slag—have been used successfully in a number of forestry trials. These materials are inexpensive, but they have serious limitations of low analysis with attendant high transportation and handling costs and of difficulty in applying because of their finely divided state. Although granulation could eliminate difficulties in application, the products would become more expensive. Source of the phosphate rock is an important consideration because there are significant differences in response of trees to applications of rock phosphate obtained from different deposits (*Bengtson 1971*).

The most favorable opportunities for use of slowly available P carriers appears to be in areas close to phosphate mining operations such as in Florida and North Carolina. They are likely to have their greatest effectiveness on acid, sandy soils

Table 5.—Composition of saturated fertilizer solutions following reaction in podzol soil

Fertilizer	P source	Composition of saturated solutions following reaction with podzol soil				
		pH	Organic matter	p.p.m.	K	Ca
11-55-0	MAP	4.2	3,070	413	600	138
18-46-0	DAP	7.2	5,730	580	70	13
23-23-0	MAP	4.1	1,760	975	825	175
27-14-0	MAP	3.9	1,280	925	115	160

Source: Unpublished data, Cominco Ltd., Trail, B. C.

with reasonable to good drainage. Under these conditions, particularly if the soils are also low in soluble Fe and Al, P supplied by water-soluble sources could be lost by leaching.

A fertilizer containing both readily available and water-insoluble P is currently being evaluated for forestry uses in the southeastern United States (*Bengtson 1971*). It is a granulated partially acidulated rock phosphate prepared at TVA. Rock phosphate-S materials are another interesting possibility because the H₂SO₄ produced by the oxidation of S will form water-soluble P (*Beaton and Fox 1971*). Unreacted phosphate rock would serve as a source of slowly available P. Mixtures of pulverized rock phosphate and 7 to 16 percent elemental S have been granulated with the aid of ball clay at TVA.

The form in which supplemental P is added to forest soils may be less critical than it is for agricultural crops. Even if water-soluble P reverts to less soluble forms, trees are probably able to utilize it through extraction by their mycorrhizal roots (*Pritchett and Smith 1969*).

Selection of a Potassium Fertilizer

The need for supplemental K can be met by several common fertilizers. These are KCl, K₂SO₄, KNO₃, and K₂SO₄.2MgSO₄. The first three materials have high K concentrations ranging between about 37 and 51 percent K (44 and 61 percent K₂O), while the latter product typically contains 18 percent K (22 percent K₂O). Because these forms of K are all water-soluble and the K will react with soil after application, any differences between sources is expected to be due to the accompanying anions.

Potassium chloride and K₂SO₄ are the two principal carriers used thus far for forest fertilization. If the price per unit of K in K₂SO₄ is reasonably competitive with that of KCl, use of the former should probably be encouraged for three

or more reasons. As indicated earlier, K₂SO₄ has a lower salt index than KCl. In addition, the Cl component of KCl may be detrimental to certain sensitive coniferous species, especially in early stages of growth. Furthermore, K₂SO₄ provides plant nutrient S, which is expected to be needed more frequently and extensively in the future.

Fertilizer grade KNO₃ was manufactured in the United States up until this year. This material is now being imported from Israel, but it is not known if deliveries are dependable. The accompanying NO₃ is probably of value to most forest species, provided it is not leached out of the root zone.

Potassium magnesium sulphate is a good source of K, S, and Mg. Because sandy soils are often deficient or low in all three nutrients, K₂SO₄.2MgSO₄ is probably the best K source on such soils.

Sulphur-coated KCl may be a practical way of reducing consumption of K, minimizing leaching losses of K on sandy or highly weathered soils, and avoiding high concentrations of troublesome Cl. Relatively new materials such as potassium metaphosphate and some of the potassium polyphosphates may also be more effective under soil conditions where leaching losses of K are substantial.

Monopotassium phosphate and its ammoniated double salt, monopotassium phosphate-monoammonium phosphate, are potentially valuable fertilizers (*Beaton 1971*) and once they are commercially available they should find their way into forest fertilization. Plans for commercial production of potassium phosphates in the U.S. were announced recently. Initially, a 9-48-16 chloride-free fertilizer will be introduced, followed by materials analyzing 0-48-31 and 5-45-29. When manufacturing facilities are completed, the products will be a 0-50-40 granular solid fertilizer and a 0-25-20 solution.

Selection of Calcium, Magnesium, and Sulphur Fertilizers

Calcium is not usually applied to forest soils, especially because soil pH is raised by the addition of common sources such as calcite and dolomite. Forest species, especially conifers, are usually quite tolerant to low pH. The benefits from reducing soil acidity are probably confined mainly to enhanced humus decomposition.

Magnesium deficiencies can probably be best corrected by application of either magnesium sulphate or potassium magnesium sulphate. Magnesium oxide can also be used, particularly in situations where there is a possibility of substantial leaching losses of more soluble forms of Mg.

The fertilizer materials containing S that have the greatest promise for forest fertilization were discussed earlier in the sections concerning N and K.

Selection of Micronutrient Fertilizers

Although favorable effects of micronutrient additions to forest lands are less common than effects from the macronutrients N, P, K, Ca, Mg, and S, an increasing need for micronutrients is indicated. Brief descriptions of some of the important sources of these plant nutrients follow.

Water-soluble inorganic salts.—Borax, granular borate, boric acid, copper sulphate, ferrous sulphate, manganese sulphate, zinc sulphate, zinc nitrate, zinc chloride, and sodium molybdate are popular water-soluble sources of micronutrients. The sulphates are the most commonly used metallic salts. They are relatively inexpensive, and they are suitable for use with mixed fertilizers. Granular sulphate salts are prepared by extrusion, compaction, or granulation by several methods. Sparingly soluble zinc-manganese-ammonium sulphite is also marketed.

Water-insoluble inorganic salts.—Metal

ammonium phosphates such as Fe, Zn, Mn, Cu, and Co having the general formula $\text{MeNH}_4\text{PO}_4 \cdot x\text{H}_2\text{O}$ have been prepared. Insoluble inorganic salts, including carbonates and oxides of Cu, Mn, and Zn, are also used.

Synthetic chelating agents.—Synthetic chelating agents form ring compounds in which a polyvalent metal ion is held between two or more atoms. Among the best-known chelating agents are ethylenediaminetetraacetic acid (EDTA), hydroxylethylenediaminetriacetic acid (HEDTA), diethylenetriaminepentaacetic acid (DTPA), ethylenediaminedi(C-hydroxyphenylacetic) acid (EDDHA), and nitrilotriacetic acid (NTA). These materials are expensive and must be at least ten times as effective as the inorganic salts to compete with them on the basis of cost per pound of micronutrient. Chelates are very useful in the formulation of liquid mixtures because they will often remain in solution.

Silvichemical complexing agents.—Natural organic complexes such as ammonium lignin sulphonate plus wood sugars and polyflavonoid chemically extracted from western hemlock bark also have the ability to complex metallic micronutrient ions. These organic complexes are generally not as effective as chelates, but they are usually less expensive. Sometimes they are not compatible with mixed fertilizers.

Fritted glasses.—Fritted micronutrients are water-soluble micronutrients that have been fused into a silicate or glass matrix; the products are compacted and granulated before bagging and storage. Solubility of the metallic salts in the frits is controlled by particle size and changes in the composition of the matrix. More than one micronutrient may be included to provide custom mixes for various crops.

Most micronutrients are applied to the soil in mixed fertilizers rather than as individual sources (*Mortvedt and Cun-*

(*nningham 1971*). Application of micronutrients alone has several disadvantages, among them are nonuniform distribution of the small amounts generally used, and increased spreading costs. Therefore, combining the micronutrient with solid and liquid fertilizers is usually the preferred practice.

PROPER RATES OF REQUIRED NUTRIENTS

Plant nutrient application rates are usually closely related to soil-stand conditions. Nitrogen rates of 112 kg./ha. or less are probably adequate for young stands before crown closure. The rates of N applied to older coniferous stands in Scandanavia and in the Pacific Northwest are customarily in the range of 168 to 336 kg./ha. of N. However, there is evidence that rates of 448 kg. of N/ha. or even higher are beneficial for the growth of Douglas-fir and western hemlock on Vancouver Island.

Nitrogen responses generally persist for 5 to 10 years. Thus applications of N at the rates referred to above would be made only every 5 years or so during the period when additional growth is desired or possible.

Soluble P fertilizers are usually applied at rates between 28 and 112 kg. of P/ha. to pine stands on the Atlantic Coastal Plain (*Bengtson 1971*), 45 to 56 kg. of P/ha. being the most common (*Bengtson 1971; Crutchfield 1969*). Less-soluble sources such as rock phosphate should be supplied at rates approximately three times that of soluble P carriers. Growth responses of southern pines to P fertilization last for at least 15 years, and as a result a single dressing may maintain satisfactory growth through a full 20- to 30-year rotation.

Supplements of 112 kg. of K per ha. were maximal for red pine in New York State (*Stone and Leaf 1967*). The beneficial effects of single applications of K have been found to be remarkably long-

lived, lasting for up to 24 years on red pine in New York.

Rates of S fertilization should probably be about 28 to 56 kg. of S/ha. for sulphate sources and approximately twice as much should be applied when granular elemental S products are used. The need for S is closely associated with the amount of N applied, and in severely S-deficient agricultural areas 1 kg. of S/ha. is added for every 5 to 7 kg. of N/ha. used. Where additions of P and S are needed, a general guideline of 1 kg. of S for each 1.3 to 1.5 kg. of P can be used for estimating S needs.

Satisfactory growth responses of conifers occurred after treatment with 25 to 75 kg. of Mg/ha. as either MgSO₄ or MgO (*Pritchett and Smith 1969*).

Because the range between B deficiency and toxicity is rather narrow, it is essential that B sources be applied uniformly to soil. Additions of from 0.25 to 3 kg. of B/ha. are generally recommended for agricultural crops. Foliar or soil applications of 15 to 60 g. of B per tree are recommended for several fruit and nut crops. Sodium borate (Na₂B₄O₇) is the most common B fertilizer.

Copper sulphate (CuSO₄) is the usual Cu supplement for agricultural crops. However, CuO, mixtures of CuSO₄ and Cu(OH)₂ and Cu chelates are sometimes used. Applications of 7 to 14 kg. of Cu-SO₄/ha. are generally recommended for most crops, and they can be effective for several years on most soils.

Soil application of from about 5 to 40 kg./ha. of Mn as MnSO₄ is the most common method of correcting deficiencies of Mn. The higher rates are often required on organic soils.

Correction of Zn deficiency can be achieved by a variety of methods, including soil and foliar applications and tree injections. Foliar applications are quite effective and are used mainly for tree crops. Applications of 3 to 5 kg. of

Zn/ha. as ZnSO₄ or ZnO are usually effective for most field crops. Response of citrus to ZnSO₄ or ZnO applied at the rate of 0.5 to 1 kg. of Zn/tree will persist for up to 5 years after application.

Iron deficiency is often more difficult to control than deficiencies of the other micronutrients. Soil applications of inorganic Fe salts have generally proved ineffective. Repeated foliar application of solutions containing 5 percent FeSO₄ at rates equivalent to 245 liters/ha. have successfully eliminated Fe deficiency in grain sorghum. Synthetic chelates or natural organic complexes containing Fe have proved helpful under some conditions, but their high cost prohibits widespread use. The chelate FeEDTA is recommended for acid soils.

The small amounts of Mo required to overcome deficiencies of this nutrient are usually added with liming mixtures and fertilizers, or as a seed treatment. Safe limits for soil application are probably considerably less than 1 kg./ha. of Mo. Foliar applications of Na₂MoO₄ have been effective under some conditions. Single applications of Mo have been found to favorably influence crop growth for the next 5 to 6 years.

ENSURE PLANT NUTRIENT SUPPLY IS ADEQUATE WHEN NEEDS ARE GREATEST

Fertilizer treatments should be timed so that plant nutrient supply is adequate when tree needs are greatest. Those factors that have the greatest influence on the timing of plant nutrient supplementation are (1) soil-forest stand condition, (2) stage of growth and management objectives, (3) seasonal differences in effectiveness of fertilization, and (4) fertilizer properties.

When levels of one or more nutrients are inadequate for new forest stands, fertilization should of course be carried out shortly before or soon after seedling establishment. If nutrient limitations do

not occur until some years after establishment, applications of the required nutrients can be postponed, but they should be made before tree vigor declines significantly. Because tree growth can be reduced by inadequate nutrition some years before distinctive deficiency symptoms appear, it is important to ensure that marginal nutrient levels are improved early rather than late in the rotation.

Stage of growth and management objectives are also important in deciding when fertilizers should be used. Beaton and MacRae (1967) proposed the following opportunities for sound use of fertilizers in the management of Douglas-fir forests on Vancouver Island:

- For tree improvement through stimulation of growth of plus trees used as sources of scions and fertilization of clone banks, seed orchards, and seed production areas.
- For maintenance of soil fertility in forest nurseries.
- For overcoming "planting check" after planting of nursery-grown seedlings, particularly on difficult sites.
- For increasing growth, after crown closure, of trees between 15 and 40 years of age.
- For increasing growth of trees within 10 to 15 years of rotation age.
- For encouraging establishment of dominance in juvenile overstocked stands when average d.b.h. exceeds 9 cm.
- For increasing the proportion and size of merchantable trees at the first commercial thinning.
- For special purposes: for example, more sapwood on pole-size trees to be used for pilings; color and vigor of Christmas trees, etc.

Some of these opportunities probably also apply to the forests of eastern North America. Fertilization is believed to have considerable potential in the Atlantic Provinces of Canada for increasing the growth rate of stands approaching maturity, for breaking stagnation in very dense pole-size stands, and in the afforestation of difficult sites.

The time of year when fertilization produces the greatest benefits should also be taken into account when planning fertilization of forests. On the basis of observations in the Pacific Northwest this writer recommends that most fertilizer materials be applied at least 3 weeks before the first flush of growth in the spring. Fertilizer dressings made during periods of dormancy are probably satisfactory just so long as the added nutrients are not leached from or immobilized in soil before the growing season begins. Most of the urea applications on forests in the Pacific Northwest are now made in the fall, starting about the second week of September.

Time of fertilizer application will also be conditioned by fertilizer properties. Sparingly soluble materials which are expected to give long-lasting responses can probably be applied at almost any time with but one qualification—that they be applied sufficiently far in advance when early season responses or responses during early stages of growth are desired. If soluble nutrients are likely to be leached from or immobilized in soil, the fertilizer materials should be applied 3 to 4 weeks before the expected initiation of spring growth.

PLACEMENT OF FERTILIZERS FOR MAXIMUM EFFECTIVENESS

Placement of fertilizers so that nutrients are positionally available may not be as important for trees, which are

long-lived and have deeper root systems than most annual agricultural crops. Forest tree species also have the capacity to utilize sparingly soluble nutrient sources. Many of the feeder roots of trees are situated close to the soil surface in forest humus layers, where they can readily absorb both recycled plant nutrients and those supplied in commercial fertilizers.

Placement of fertilizers in forestry situations is usually done during the site-preparation process for new stands. Phosphate fertilizers are often mixed into soil of the planting beds to improve seedling survival and to encourage early root development and tree growth. On soils with low P-fixing capacity, and where leaching of soluble P is not a problem, placement of fertilizer P is not critical. Incorporation or placement of fertilizer P is recommended on soils subject to drought.

Preparation of sites being planted to loblolly pine in the Atlantic Coastal Plain commonly includes placement of P in the bed. For example, approximately 44.5 kg. of P/ha. as concentrated superphosphate is broadcast after an area has been cleared but before bedding (Wiley *et al.* 1970). Both a wheeled skidding tractor equipped with a hopper-spreader and a helicopter have been used to broadcast the P fertilizers. The former type of equipment is favored in some instances because of more uniform application.

Broadcast application of N or other nutrients to established stands is equivalent to topdressing of agronomic crops. Aerial applications are often the only practical method of topdressing extensive areas of established stands because it is virtually impossible to drive fertilizer application equipment through most forest stands. Ground application is feasible only for small areas or where thinning techniques such as corridor thinning permit some degree of access.

AERIAL FERTILIZATION

Fixed-wing airplanes and helicopters are the main types of aircraft used for spreading fertilizers on forests. At the outset, use of helicopters was discouraged because of high application costs. However, due to great increases in payload capacity and improvements in spreaders and in fertilizer-handling systems on the ground, helicopter spreading costs are now competitive with those of fixed-wing aircraft, about 2.2 to 2.8 cents per kg. of fertilizer.

With fixed-wing airplanes, the economics of application are best with short flying distances—approximately 4.8 km. from runway to point of application. In areas too distant from conventional landing strips, "Kiwi" inclined airstrips can be constructed. Crown (1971) described one such strip that was built during the winter of 1968 in the Robertson River Valley on Vancouver Island. The site selected was at 335 m. above sea level and 152 m. above the valley floor. The strip was 256 m. long, including a loading area at the top of the slope. The lower two thirds of the runway had an 8 to 10 percent slope, while the upper third averaged 12 percent. Construction costs of the six inclined airstrips built up to the middle of June 1971 in coastal regions of B. C. ranged from \$160 to \$1,700.

Helicopters offer one important advantage in that they can take off and land in small clearings or on logging roads. The most popular helicopter systems use a

pod or conical tank carried under the helicopter on a sling (*Page and Gustafson 1969*). The pod has a mechanism to meter fertilizer to a spinner that broadcasts fertilizer as the helicopter moves over an area. Spreader equipment may be driven by electric or hydraulic motors powered from the helicopter or by a radio-controlled gasoline engine mounted on the side of the pod.

Because of the high operating costs of helicopters it is essential that turn-around time at the landing point be minimized. The most efficient systems for reloading helicopters make use of two pods. One pod is refilled while the helicopter is spreading the load from the other.

It is desirable to have an adequate supply of fertilizer materials on hand well in advance of the spreading operations. One of the most satisfactory methods is to stockpile the required amounts of bagged fertilizer at each loading site 2 to 3 months before application. After testing numerous containers and systems for handling urea in the Pacific Northwest, 90-kg. bags of 7- or 8-ml. polyethylene seem to be the most suitable.

Air turbulence may make it difficult to obtain uniform application of fertilizers from aircraft, especially from helicopters. A large (-4+6 mesh) granular urea product has been developed in the Pacific Northwest to overcome this spreading problem. Ammonium nitrate of very large particle size is produced and marketed for forest fertilization in Norway and Sweden.

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WATER-QUALITY—LIMNOLOGICAL CONCERNS ABOUT FOREST FERTILIZATION

by ROBERT G. WERNER, Associate Professor, State University of New York College of Environmental Science and Forestry, Syracuse, N. Y.

ABSTRACT. From the viewpoint of a limnologist, the author discusses possible effects of forest fertilization on the aquatic ecosystems of streams and lakes and raises a number of questions for consideration. Since forest fertilization is still in its infancy, we should begin an intensive search for answers to these questions, hoping that the fears of limnologists may be unfounded.

WE ARE ALL aware of the serious threat posed by water pollution to our lakes and streams. Much of the supply of relatively clear uncontaminated water lies in forested areas. Consequently, limnologists look with some concern at the recent appearance of forest fertilization as a potential threat to the quality of these clear waters.

Since I am a limnologist and know little about soil chemistry, I will simply make what I presume are reasonable assumptions about what one could expect as inputs into the aquatic ecosystem as a result of forest fertilization. These are:

(1) Fertilization will result in an increase in the concentration of nutrients entering streams and lakes, both those nutrients that are applied and possibly others that may be released from the soil. The magnitude of the increase is undetermined and will vary with soil types,

slope, amount of precipitation, vegetation, and a host of other variables.

(2) There will be an increase in the rate of productivity both in the target species and other plant components of the forest, which will result in an increase in the input of dissolved and particulate organic matter into the stream or lake.

Little is known about the impact of forest fertilization on lakes and streams. Recent work at Hubbard Brook (*Likens et al. 1970*) has shown that cutting over and chemically treating watersheds can have profound effects on water quality. It seems reasonable to expect that forest fertilization might also affect water quality. However, investigations of this nature are limited. One approach might be to draw analogies between agricultural fertilization and forest fertilization. The relationship between agricultural fertili-

zation practices and water quality have been much more thoroughly investigated (*Sawyer 1947*). However, it could be misleading to try to draw parallels.

Farm crops are grown on bare soil unprotected from rain, whereas forest land is usually protected from erosion. Rarely if ever does the farm crop keep the stream in shade as the forest does. Frequently the forested land is in areas where the slope and soil are such that farming would be impossible. Consequently, drainage patterns would be quite different. Thus it seems that forest fertilization is unique enough to require a separate analysis.

Since relatively little work has been done on the effect of forest fertilization and water quality and no long-term work comparable to the time needed to prepare a forest crop for harvesting, I shall simply speculate on what possible consequences might occur and attempt to raise questions from a limnologist's point of view.

FOREST FERTILIZATION AND STREAMS

Streams are characterized by longitudinal gradients in terms of temperature and chemical constituents and exhibit very little vertical stratification. Upstream areas are generally cooler and contain lower concentrations of dissolved compounds than downstream reaches. However, due to the turbulent flow exhibited in streams, there is rather good mixing with reasonable uniformity from bank to bank and from surface to stream bottom (*Hynes 1970*).

Turbidity levels are frequently high in streams, particularly during high flows or in areas disturbed by man. In forested watersheds, turbidity levels are lower. High turbidity tends to reduce productivity by reducing the amount of light reaching the stream bottom. However, in those areas where the forest canopy completely encloses a small stream, light

reaching the stream is already greatly reduced. In coniferous forests this condition would persist year round. In deciduous forests increased light would be expected in the spring before the leaves appear and in the fall after leaf fall. Summer would be the period of minimal light for stream plants (*Minckley 1963*).

Water entering a stream is derived from either surface sources or through underground flow. During periods of heavy rain or snowmelt, surface runoff adds considerably to the volume of water in the stream. However, during most of the year, water that has percolated through the soil is the primary source. This explains why the concentration of dissolved solids is highest in low-flow periods and lowest during spate conditions. Conversely, the total quantity of material removed from the watershed is often highest during periods of heavy rain or snowmelt and lowest in the dry part of the year.

Terrestrial vegetation plays a role also, in that it slows down the movement of water into the stream, thus reducing the load of particulate matter and increasing the proportion of dissolved matter. This results from the reduction in water velocity due to the intercepting effect of the vegetation. In forested areas very little surface flow would be expected.

Plant nutrients enter a stream directly through material dissolved in rainwater, by leaching from the soil and bedrock, and through decomposition of organic matter, such as leaves, carried in from the watershed. The input resulting from rainwater is not small (table 1), particularly when compared to minimum values of some Wisconsin lakes. It is clear that a basin filled with rainwater would make a reasonable approximation to some existing soft-water lakes (*Hutchinson 1957*).

The contribution made by allochthonous organic matter, although frequently overlooked, can also be considerable. Chandler (1941 and 1943) estimated the N return to the soil from leaves at 23.6

Table 1.—Chemical composition of rainwater and water in dilute Wisconsin lakes (from Hutchinson 1957)

Compound	Rainwater <i>Mg./l.</i>	Minimum concentration, Wisconsin lakes <i>Mg./l.</i>
C1	0.5	0.1
Br	.03	—
I	.001	—
SO ₄	2.0	.75
B	.01	—
Na	.4 +	.13
K	.03 +	.25
Mg	.1 +	< .5
Ca	.1-10	.13
N NH ₃	.5	< .01
N NO ₃	.2	< .004

pounds per acre for conifers and 16.6 pounds per acre for hardwood forests. The values for phosphorus were 1.8 and 3.3 pounds per acre for conifer and hardwood forests respectively. Of course, much of this is recycled within the forest ecosystem, but a significant portion also enters the aquatic ecosystem (Teal 1957). Probably the major pathway for nutrient uptake by the stream, however, is through leaching of the soil and bedrock.

Plants in streams require approximately the same array of nutrient salts as their terrestrial counterparts: K, N, and P, along with a large number of minor elements such as Fe, S, Si, etc. Neither K nor any of the minor elements has been shown to be a factor limiting plant growth in streams (Hynes 1970). As a result, N and P are the elements of particular concern to limnologists.

P is tightly held by the soil, and relatively little leaching occurs (Donahue 1965). Many investigators feel that the major port of entry is via soil particles themselves. Owens and Johnson (1966) have suggested streambank erosion as a major source; others feel that silt transported in during high-flow periods may bring in P. In undisturbed forested areas where little erosion occurs, the addition of P in this manner would probably be slight.

N is more readily leached from the soil

and, in addition, some forms of algae (*Nostoc* and *Rivularia*) have the capability of fixing atmospheric N.

Potentially, at least, the stream could draw its nutrients from the entire upstream drainage basin. The area drained by a given section of stream has been estimated, and on the average 1.0 square km. of drainage area supports 1.4 km. of stream (Leopold *et al.* 1964). Since streams are relatively narrow and have considerably smaller surface areas than the basins they drain, they may receive rather large inputs from small amounts of leaching per unit area of drainage basin.

For example, suppose a headwater stream 2 m. wide and 1.4 km. long drained an area of 1 km². It would be draining an area of 1,000,000 m², whereas its area would be 2,800 m²—a ratio of 357:1. If this drainage basin were fertilized at a rate of 100 kg./ha., less than 0.3 kg./ha. would have to be lost to the stream to have the same impact as direct fertilization on the stream surface at a rate of 100 kg./ha. This value would vary, of course, with streams of different widths. Consequently, the potential of accumulating small quantities of nutrients from a large drainage area into a small stream must be borne in mind when interpreting leaching results.

Efforts have been made to estimate the productivity of the plant community in

unpolluted streams. In most cases the conclusion was reached that the plants in the stream were producing just enough energy for their own needs and that very little if any excess was being produced (*Nelson and Scott 1962; Hoskin 1959*). Heterotrophy, then, is dependent, to a large degree, on allochthonous imports of organic matter. Such things as leaf litter, particulate and dissolved organic matter from the soil, and terrestrial animals are major sources of energy for the stream heterotrophs.

With this as a background, we can begin to examine some of the limnological consequences of forest fertilization.

To begin with, a relatively small (< 1 percent) removal of fertilizer through leaching and subsurface flow could lead to substantial quantities being transported to the stream. Cole and Gessel (1965) estimated nutrient loss to the 3-foot level in porous soils on the West Coast, using tension lysimeters after fertilization with ammonium sulfate and urea. Their results indicated a slight increase in N levels at the 3-foot level over controls. The increase was about 0.07 to 0.23 percent of the N applied as fertilizer.

If one could assume that all the N that reaches the 3-foot level could move with the ground or subsurface water to the stream unhindered and use the stream area/drainage area relationship previously discussed, this then would be equivalent to fertilizing directly on the stream surface at a rate of 164 pounds per acre of ammonium sulfate or 50 pounds per acre of urea. This probably doesn't happen, but it is clear that we need more information about the fate of nutrients after they pass through the rooting zone and enter the subsurface or ground water.

But assume the worst, and imagine that large quantities of nutrients do reach the stream from fertilization: What would be their impact? One of the few direct attempts to study this was an effort by Huntsman (1948). He placed bags of

fertilizer in streams and sprinkled large amounts on the stream bank and then measured the effect on the stream biota. His conclusion was that fertilization increased population levels of algae, which led to a subsequent increase in bottom invertebrates and fish populations. However, the surprising result was that the impact of this extended for just a short distance downstream. The maximum distance that any observable effect was noted was 150 yards from the point of fertilization.

Other workers (*Neel 1951; Minckley 1963*) have noted rapid uptake of plant nutrients in the stream, attributable to plant activity. Such a phenomenon, if borne out by more careful study, would lead to the conclusion that high concentrations of nutrients might develop in very restricted areas, characterized by high algal populations and high productivity. So, not only is it important to know the distance travelled by nutrients underground, but how extensively and—more importantly—how rapid are their movements in the open stream channel? It is clear that ultimately they must move downstream. Very few mechanisms exist for transporting nutrients upstream save migrations of biological material such as fish or mayflies. Consequently, the rate of downstream movement over the long term would be of particular interest.

What role does light play in all this? Phinney and McIntyre (1965), working with stream algae in artificial channels, have shown that productivity (measured as net oxygen production) was highest at 11,400 lux at 18°C. Below this, productivity dropped until at 620 lux more oxygen was being respired than produced. Since nutrient demand would be related to photosynthetic rate, the uptake of nutrients by stream plants in a shaded forest stream might be inhibited at low light intensities. This could have important implications for downstream movement of nutrients and possibly lake eutrophication.

cation. Unfortunately, we know very little about this aspect of stream limnology.

Another facet that should be investigated is the relationship between increased terrestrial plant growth and the input of allochthonous organic matter to the stream. If fertilization results in increased terrestrial productivity, will this lead to increases in the quantity of dissolved and particulate organic matter entering the stream? Organic matter from leaf fall would raise the BOD (Biochemical Oxygen Demand) and might be expected to reduce oxygen concentrations in still pools. On the positive side, trout feed heavily on terrestrial insects washed into the stream (*Reed and Bear 1966*). If fertilization increases terrestrial insect production, it may also improve trout production.

FOREST FERTILIZATION AND LAKES

Lakes, in contrast to streams, act as catchment basins, accumulating materials in the sediments, which can sometimes be recycled. Recycling is hampered by several things, but most important is the fact that lakes are vertically stratified during the warm growing season. In the summer a warm well-mixed layer, usually high in oxygen and low in nutrients and carbon dioxide, rests above a cold dark layer, sometimes low in oxygen and usually high in nutrients and carbon dioxide.

The upper layer (epilimnion) is the zone of high photosynthesis, which normally fixes more energy than can be consumed by the heterotrophic components of the ecosystem. The lower layer (hypolimnion) is usually dark and thus fixes little energy, but does consume the production of the epilimnion, releasing nutrients in the process. The two layers are separated by a transition zone called the metalimnion, which inhibits mixing until fall turnover.

The summer stratification period in

the Northeast may last from April through October, depending on the latitude, morphometry of the lake basin, and weather. This, of course, is the period of greatest biological activity and the period during which many forest-management practices, such as fertilization, are likely to occur.

The epilimnion is the only layer that has contact with the atmosphere throughout the period of stratification. It is usually well mixed and consequently well oxygenated. In this zone most of the photosynthetic activity takes place, also contributing oxygen to the water and frequently depleting carbon dioxide. Nutrients utilized by the algae are to a certain extent recycled within the epilimnion, but a substantial fraction is removed from the epilimnion in the form of the dead bodies of organisms, which settle into the deeper portion of the lake.

Here decomposition processes release the nutrients, using oxygen in the process. The hypolimnion then becomes enriched with nutrients, which are not available to the plants in the lighted epilimnion. It also may become anoxic as a result of the respiratory demands of the heterotrophs and the fact that it has no source of resupply, either from contact with the atmosphere or from photosynthesis.

In a sense the lake may have a kind of limit on its productivity during the stratification period. Since nutrients are lost to the hypolimnion as a result of production, late in the stratification period the lack of certain key elements may act to inhibit productivity. Inputs of nutrients from the drainage basin either via stream flow or underground flow may, of course, supplement some of these losses. On occasion, certain vital nutrients such as P can be trapped in the hypolimnion when Fe is present.

What impact would forest fertilization have on standing bodies of water? To begin with, we would expect an increase in nutrients entering either via under-

ground seepage similar to streams or through streamflow. An increase in nutrients would speed up the rate of eutrophication.

The eutrophication process is well known (*Hasler 1947; Sawyer 1966*). It begins with an increase in plant density, which leads to increased production of all trophic levels. The quantity of organic matter settling into the hypolimnion increases, leading to higher BOD's. Eventually, a time is reached when respiratory demands exceed the hypolimnetic oxygen supply, and the hypolimnion becomes anoxic. In severe cases, particularly in the winter, when the lake has a thick blanket of snow, the entire lake can become anoxic.

For example, Ball (1950) added inorganic fertilizer to two lakes in Michigan at a rate of 100 pounds per acre, four or five times during two consecutive growing seasons. Two neighboring lakes were retained as controls. The fertilizer was 10-6-4, high in N and P. Fertilization increased algal biomass in both lakes for two years subsequent to the introduction of the fertilizer. In addition, during the second winter, both lakes suffered a winterkill; oxygen became sufficiently depleted in the lake under the ice that large numbers of fish died as a result. Winterkill was not experienced in the control lakes.

Thus it is clear that in small lakes at least the addition of fertilizer in concentrations similar to what one would put on the land could have drastic effects, particularly in the Northeast, where winters are long and are characterized by heavy snowfall.

Even if winterkill is avoided, other unpleasant effects might be expected. Such things as a reduction in water clarity, occurrence of algal blooms, and low oxygen in the hypolimnion, leading to a loss

of cold water fishes such as trout, are all possible consequences of the eutrophication process.

DISCUSSION

A completely efficient forest-fertilization program would convey all nutrients added to the soil into harvestable tree tissue. If this happy circumstance occurred, the water-quality problem would disappear. Unfortunately, this is unlikely to be the case. Therefore there is an urgent need to answer several vital questions.

(1) How far are nutrients transported in the subsurface water and ground water? (2) What is the effect of soil type and slope on the loss of nutrients? (3) What types of management practices might reduce the loss of nutrients to the stream?

Aquatic ecologists are faced with several questions also. (1) What happens to fertilizers that enter the stream, particularly N and P? What forms do they take? Where can they be found? Are they available to plants? (2) How far and how rapidly downstream are nutrients transported? (3) What is the impact of shading on the downstream movement of nutrients? (4) What role does an increase in allochthonous organic matter have on the stream ecosystem? (5) In lakes, what will be the impact of forest fertilization on the natural eutrophication process? Would winterkill result? (6) Are there positive benefits to be derived such as increasing fish production?

It seems to me, since forest fertilization is still in its infancy, but showing signs of robust growth, that we should begin an intensive search for answers to these questions. I hope we shall discover that the fears of the limnologists are unfounded.

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POTENTIAL IMPACT OF FOREST FERTILIZATION ON STREAMFLOW

by JAMES W. HORNBECK and ROBERT S. PIERCE,
Research Foresters, USDA Forest Service,
Northeastern Forest Experiment Station,
Durham, N. H.

ABSTRACT. Forest fertilization may cause a decline in quantity of streamflow by stimulating additional leaf surface area and root occupancy, thus increasing water losses to transpiration and interception. Water quality may be affected by application of fertilizers directly into stream channels and by an increase in the amount of nutrients transported to the stream by subsurface flow. The magnitude of increases in nutrients in subsurface flow will depend on such factors as type and form of fertilizer nutrients applied, efficiency of root uptake, and water regime and cation exchange capacity of the site. The use of gaged watersheds appears to be the best method for quantifying the potential impact of forest fertilization on streamflow.

THE CONTINUING CONCERN over environmental quality suggests to us that forest fertilization must not be attempted on any large scale without first considering the potential impact on quantity and quality of streamflow.

We have virtually no documented evidence about how forest fertilization might affect streamflow in eastern North America. However, a background of forest hydrology and soils information and past experiences in agriculture are available to draw upon for at least an initial discussion of the potential impact of fertilization. We have chosen information from these sources to point out some considerations that must be made about fertilization and streamflow.

QUANTITY OF STREAMFLOW

Studies of forest hydrology have some implication about forest fertilization and quantity of streamflow. Gaged-watershed studies have demonstrated that reduction of forest cover results in proportional increases in quantity of streamflow (*Hibbert 1967*). These studies show that increases in streamflow decline as the forest regrows and that the rate of decline varies, depending on how rapidly revegetation occurs.

The decline in streamflow during the regrowth cycle is due to accumulation of biomass in the new forest, particularly as foliage and roots, thus increasing water losses to transpiration and interception

(less than 1 percent of the water uptake by trees is stored in biomass). As the stand regrows, actual evapotranspiration approaches the potential or maximum possible evapotranspiration for the site, the result being less water available for streamflow. The corollary for forest fertilization is that increases in biomass due to fertilization may possibly be accompanied by increased evapotranspiration and a decline in streamflow.

A study at the Coweeta Hydrologic Laboratory in North Carolina showed that quantity of streamflow will respond to fertilization (*Hibbert 1969*). A mountainous 9-hectare watershed was converted from hardwood forest cover to grass and heavily fertilized. During the first year under grass, water use was essentially the same as that by the original forest. In succeeding years, however, the productivity of the grass declined as fertilizer reserves were exhausted. By the fifth year after conversion to grass, the watershed was yielding 150 mm. per year more water than would have occurred from the original forest.

At this point in the experiment the grass cover was again fertilized and restored to original productivity. Annual water use immediately returned to about the same level as used by the original forest. Thus by withholding or applying fertilizer, annual streamflow was varied over a 150-mm. range.

The significance of this experiment lies in the strong relationships between streamflow and biomass production as stimulated by fertilization. The results have only indirect application for forests that vary greatly from grasses in transpiring surface, physiological response, and root occupancy. Information is limited as to how forest fertilization will affect the biomass components of hydrologic interest such as leaf surface area and rooting.

In perhaps the most appropriate study available, Heilmann and Gessel (1963) found that N fertilization applied to rela-

tively poor soils caused foliar material in Douglas-fir stands to increase 20 to 53 percent. Safford (1972) noted that the fine root biomass doubled under a 90-year-old beech-birch-maple forest in New Hampshire after heavy application of lime (1,120 kg./ha.) and 15-10-10 N-P-K fertilizer (6,720 kg./ha.).

We can also infer from studies of site productivity that site improvement by fertilization will increase the amount of leaf surface area. Leaf and Leonard (1969) reported growth characteristics of 30-year-old red pine on a medium productive site versus a site with severe K deficiency. The medium productive site had a needle mass weighing over 11,000 kg./ha. and a needle surface area of 12 hectares per hectare. Needles on the K-deficient site weighed only 5,500 kg./ha. and had a surface area of about 7 hectares per hectare. The medium productive site was estimated to intercept 10 percent more precipitation than the K-deficient site.

Ovington (1965) found that a greater weight of leaves tends to be present in forests on better soils. Whittaker's (1966) detailed ecological studies in the Great Smoky Mountains indicated that leaf surface area for both hardwood and conifer species will increase as growing-site conditions improve.

From studies such as these it does not appear unrealistic to anticipate that improvements in site conditions through forest fertilization will increase both leaf surface area and root occupancy and in turn bring about an increase in water use.

Many factors will affect the magnitude of changes in water use that might result from fertilization. One of the most important will be the age of the stand at fertilization. Consider three periods when fertilizer application is likely: (1) near harvest, (2) before crown closure, and (3) after crown closure. Near harvest, the actual evapotranspiration for the stand is usually closest to potential, and the pos-

sibility for significant increases in water use will be at a minimum. Also, biomass increases resulting from fertilization of older stands will be more in the form of woody material than foliage (*Kawana 1966*).

Fertilization before crown closure increases leaf area and hastens crown closure. And since evapotranspiration at earlier ages will normally be furthest below potential, chances for increasing water use will be at a maximum. Effects of fertilization at some point after crown closure can be expected to be intermediate to the above two conditions, depending on the length of time since closure.

If forest fertilization increases water uses, what will be the impact on the fertilized area and areas downstream? First, there will be less water to move laterally through the soil to the stream, and thus leaching losses may be reduced. For example, a reduction of 1 cm./year of streamflow that would have transported 10 to 20 mg./liter of dissolved solids would result in several kg./ha. of nutrients remaining on site. Another advantageous impact may be greater availability for moisture storage, thus creating potential for reducing stormflow volume. A detrimental impact would be a lesser volume of water being available for downstream use.

Determining changes in quantity of streamflow due to fertilization may prove both expensive and difficult, particularly since the magnitude of the changes will probably be small. The two most feasible methods appear to be to monitor soil-moisture data (*Cope and Trickett 1965*) and to use paired gaged watersheds (*Wilm 1944*). Soil-moisture data may be useful in detecting increased water use due to fertilization, but they cannot give a direct measure of streamflow as compared to gaged-watershed data.

The neutron scattering technique is presently the favored way of monitoring soil-moisture data. However, the standard error is of the magnitude of daily

evapotranspiration (*Federer 1970*), and this method could be used only for studying changes in water use that accrue over long intervals of time.

Because of the lag in moisture movement through the soil to the stream, the gaged-watershed technique is good only for determining streamflow changes over a month or more. However, when careful control is maintained, this method can detect changes of a centimeter of streamflow per month. An added advantage is that this method allows simultaneous determination of effects of forest fertilization on water quality. Both methods will present special problems in the event that the stand in question is in a period of rapid regrowth. The proportion of the increase in water use due to natural regrowth and that due to added growth from fertilization will be difficult to separate.

We must put the potential changes in quantity of streamflow in perspective. On a regional basis, it is doubtful that any changes in stream quantity would be noticeable unless extremely large proportions of the area were fertilized. On a local basis, such as where smaller forested watersheds feed a lake or a municipal water supply, a decline in streamflow due to fertilization might be of some consequence, especially during the late growing-season months when streamflow is usually at a minimum.

QUALITY OF STREAMFLOW

Over the past few years a lively controversy has developed over whether or not agricultural fertilizers impair water quality. Ecologists have expressed concern that a sizable proportion of nutrients applied as fertilizers are being leached or eroded into surface and groundwater systems, causing eutrophication and toxicity problems (*Kohl et al. 1971; anonymous 1969*).

On the other hand, Viets (1971) reasoned that fertilizers reduce sedimenta-

tion and area in cropland, so he began his paper with the statement: "Commercial fertilizers improve water quality."

Like it or not, forest fertilization is being caught in this same controversy. But unlike agriculture, forest fertilization is still basically in its infancy. At least in the Northeast, forest fertilization has not progressed much beyond a few field trials. So we still have the opportunity to research and evaluate the impact of forest fertilization on water quality before large-scale applications are made.

There are three major means by which nutrients applied as fertilizers can reach the stream channel: (1) application directly into the stream, (2) incorporated with organic and inorganic materials eroded or blown into the stream, and (3) solutes or sediment in water moving as either overland or subsurface flow.

Fertilizers that fall directly into the stream channel during application will produce an immediate and measureable response. However, with a degree of care in application, the amounts involved should not be of concern, and any effects should be short-lived.

The importance of nutrients incorporated with eroded and wind-blown material is unknown. Erosion usually is a negligible factor from forests, particularly if the stand is established. A problem may arise if fertilizer is applied at the start of a new rotation, when chances for erosion are maximum because of more moist soils and greater areas of exposed mineral soils from logging. If we follow Viets' (1971) reasoning, fertilizers may actually reduce erosion losses by generating additional biomass and thus added soil protection.

Overland flow is rare in forests and ordinarily will not be an important source of transport for fertilizer nutrients. Subsurface flow, on the other hand, is the pathway for the major volume of water reaching the stream channel. As a result, transport of nutrients by subsurface flow, usually termed leaching, will normally be the means by which the greatest propor-

tion of fertilizer nutrients reach the stream.

Established or undisturbed forests are usually efficient at preventing leaching of nutrients (*Cooper 1969*). This is true even though forests commonly occupy sites conducive to leaching. Studies of nutrient cycling in hardwood forests of central New Hampshire provide an illustration. The study area is located on steep slopes with thin sandy-loam podzol soils and receives abundant precipitation, but the streams draining undisturbed forest seldom have total ionic concentrations exceeding 20 mg./liter. However, removal of the forest cover quickly increased nutrient leaching and raised annual stream ion concentration to nearly 80 mg./liter (*Likens et al. 1970*).

In addition to having low leaching losses, forest ecosystems also seem to have the capacity for accumulating and retaining added nutrient ions. The best example is an experiment at Pennsylvania State University, in which forests have been used to renovate treated sewage. Effluent containing an average 12 mg./liter of organic and nitrate N and 8.5 mg./liter of P was applied in frequent 2.5- and 5-cm. irrigations to a natural hardwood stand and a red pine plantation located on deep sandy-loam soils. Soil percolate measurements indicate that 62 to 85 percent of the N and virtually all the P were retained in the surface 30 cm. of soil (*Pennypacker et al. 1967*).

Further illustrations have been provided by various forest-fertilization studies. In a study using tension lysimeters, Cole and Gessel (1965) found that during the first 10 months after fertilization of a Douglas-fir plantation on coarse-textured soils in Washington, nutrient losses by leaching were small, although the levels of N, P, K and Ca in the leachate were 1.3 to 4 times greater than the low initial levels.

Moore (1970) reported that fertilization of Douglas-fir in southwest Oregon

with urea at 224 kg. N/ha. caused stream-water concentrations of urea, ammonia- and nitrate-N to increase only slightly above background values. By the fourth week after application, all forms of N in the stream had returned to pretreatment levels.

Nearly identical results were found after urea applications to forests on both clay-loam and sandy outwash soils of the Capitol Forest near Olympia, Washington (*McCall 1970*), and to a 35-year-old Douglas-fir tract in the Cascade Mountains of Oregon (*Malueg et al. 1972*).

A study using tension lysimeters in northern Quebec indicated leaching losses of less than 1 kg./ha. during the growing season after urea fertilization at 444 kg.N/ha. in a dense black spruce stand growing on a podzolic soil with a thick raw humus layer (*Roberge et al. 1971*).

These studies provide an indication that established forests will be able to receive added nutrients in the form of fertilizers without greatly increasing leaching to streams. To avoid abusing this capability, consideration must be given to a

number of important variables that affect nutrient leaching. These variables, which serve to influence the path nutrients follow in the soil environment (fig. 1), include type and form of the fertilizer nutrient, efficiency of root action, water regime of the site, and cation exchange capacity.

Type and form of nutrients.—Although a variety of nutrient deficiencies may occur in forests (*Leaf 1968; Stone 1968*), the majority of fertilizer applications have been limited to the three major elements: N, P, and K. Of these three, additions of P will be of least concern in regard to water quality. Practically all P applied as fertilizer is converted to water-insoluble forms within a few hours (*Taylor 1967*). This immobilization is due to the strong adsorption of P by finely divided soil mineral particles (fig. 1). The P-fixing power of forest soils in the Northeast is usually so enormous that the main concern is not with leaching losses but with freeing P for plant use.

K exhibits a strong tendency to be reincorporated into solid weathering products, especially certain clay minerals.

NUTRIENT PATHWAYS

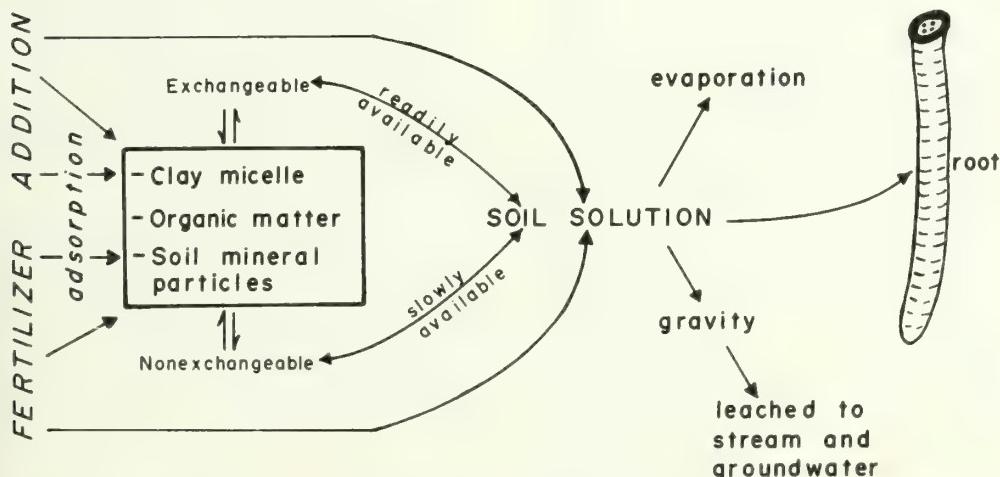


Figure 1.—Some of the forces acting on fertilizer nutrients.

Thus K is relatively immobile in most soils but sometimes may be leached from acid sandy soils (Allen 1968). A review of K movement in soils by Munson and Nelson (1963) indicated that fertilizer formulated as potassium calcium pyrophosphate ($K_2 Ca P_2 O_7$) will minimize K leaching from acid sands. The commonly used potassium chloride (KCl) appears to be the formulation most susceptible to leaching losses.

N fertilizers, because of the large volume applied and ease of solubility, represent the greatest hazard to water quality. Depending on formulation, N fertilizers have potential for increasing stream concentrations of urea, ammonium- and nitrate-N, and total organic N. Leaching of nitrate, which as an anion is not tightly held by the soil exchange complex, constitutes one of the main pathways for loss of N from soils (Allison 1965). Ammonium-N, which is a cation, presents less of a leaching problem.

Certain N formulations may create secondary leaching problems by increasing soil acidity. For example, compounds supplying the ammonium form of N may undergo the following reaction:



The H^+ ions produced in this reaction can free other cations for leaching to streams by replacing them on the soil exchange sites.

Efficiency of root action.—Efficient nutrient uptake depends on distribution and activity of the rooting system and its associated microorganism population, including mycorrhizal fungi. Recently harvested stands, species or sites with poor root distribution, and dormancy are some obvious conditions under which uptake may be less than optimum. In such cases added fertilizer nutrients may be more susceptible to leaching.

Water regime.—The amount of water moving through the soil and capable of

transporting nutrients will depend in part upon rainfall intensity, duration, and frequency. The possibilities for leaching losses will generally increase as the excess of precipitation over evapotranspiration becomes greater.

Soil textural class and structure, position on slope, and vegetative cover as they affect infiltration and percolation, will also have major influences on nutrient leaching. If these characteristics combine to prolong residence time of soil water, there is greater opportunity for nutrients to solubilize and be transported to streams.

Cation exchange capacity (CEC).—The ability of a soil to retain applied nutrients will depend to a large degree on its CEC. Organic matter and the clay fraction are primarily responsible for CEC and act to retard nutrient movement and leaching (fig. 1). The organic-matter content of mineral soils may range from 0.1 to 5 percent or more and can account for 30 to 60 percent of the exchange capacity (Jones 1947). Organic materials composing the forest floor also provide some exchange capacity. In northern hardwood stands and in strongly podzolized soils, the forest floor may constitute the major proportion of the CEC (Wilde *et al.* 1949).

Both amount and type of the clay fraction influence CEC. The CEC of montmorillonite, hydrous mica, and kaolinite are more or less in the order of 100, 35, and 10 millequivalents per 100 grams, respectively.

Determinations of clay fraction and organic-matter content are relatively straightforward and accurate for most soils and can provide valuable information on the potential for leaching of fertilizer nutrients. Considering factors such as those mentioned will aid in determining the type and rate of fertilizer and the time of application that will be least likely to cause changes in water quality.

EVALUATING THE IMPACT ON WATER QUALITY

Either small watersheds (*Bormann and Likens 1967*) or lysimeters are the best for evaluating potential changes in water quality resulting from forest fertilization. Comparing the two approaches, the advantages of lysimeter studies include somewhat less expense, quicker results, and a better opportunity to replicate experiments in terms of location and types and amounts of fertilizers applied. But lysimeters also have serious drawbacks. They can be used to evaluate changes in soil leachate, but these results then have to be extrapolated in terms of how surface streams will be affected.

Also, a major criticism is that lysimeters of all types (both filled-in and monolith types) containing undisturbed soil are to varying degrees artificial systems (*Allison 1965*). They have abnormal and limited water movement in comparison to actual soil profiles. Tension-plate lysimeters were designed to overcome this problem (*Cole 1958*), but they have also led to difficulty in accurately quantifying nutrients leached within the soil profile (*Cochran et al. 1970*).

Nutter and Ike (1970) have pointed out that lysimeters can only sample discrete sections of the hydrologic continuum from stream to ridgeline. Streamflow and the nutrients it transports are generated from this continuum in a non-linear composite fashion, depending on distance from stream, antecedent moisture, and other factors; so it is particularly difficult to make a meaningful extrapolation of lysimeter results to larger areas.

Small watershed studies overcome many of the disadvantages of lysimeters. The effects of fertilization on water quality can be measured directly by stream sampling (*Nelson 1970*). And there will be fewer problems with interpretation of results as the watershed approach provides an integration of all variables acting to influence nutrient leaching to

streams. If the watershed is gaged, then streamflow measurements can be used with chemical-concentration measurements to determine nutrient losses from the basin in terms of mass per unit area or time.

The main disadvantages to using gaged watersheds are the expense in both time and money and the fact that replication of an experiment can seldom be afforded. For these reasons, careful planning and implementation are essential when using gaged watersheds to study effects of any kind of forest treatment on streamflow.

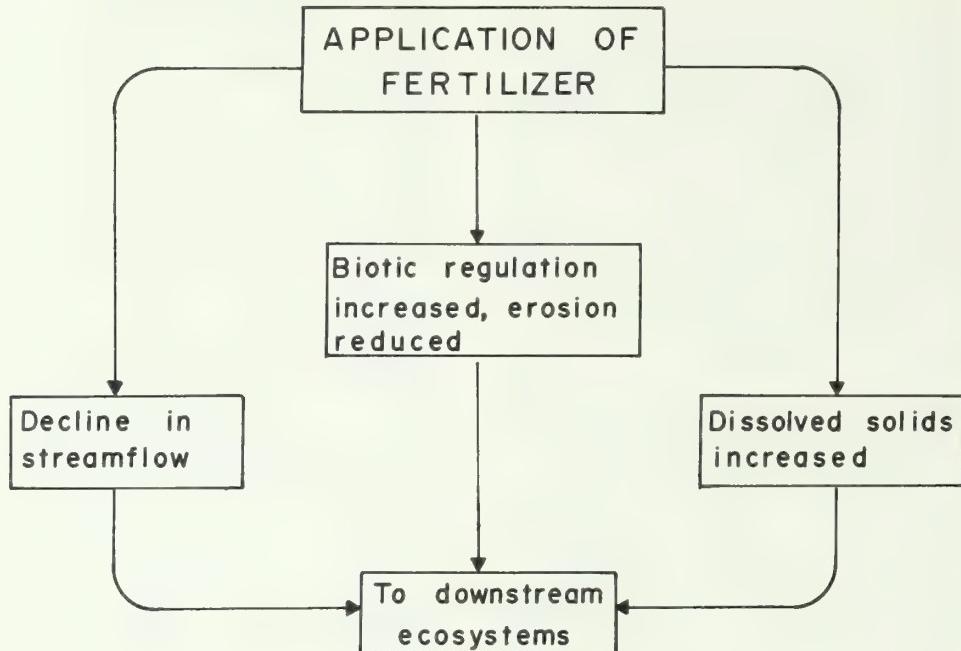
At the Hubbard Brook Experimental Forest we have a hardwood forested watershed that has been carefully calibrated for both water quantity and quality, and it will soon receive a fertilizer application. Since we do not have extra watersheds for any additional fertilizer experiments, we are finding that seemingly simple decisions such as form and rate of fertilizer to apply are really agonizing. It now appears that we will want to supplement our gaged-watershed study by testing additional forms and rates of fertilizers either on ungaaged watersheds or with lysimeters.

CONCLUSION

By drawing inferences from various sources we can speculate about the potential impact of fertilization on streamflow. Three major areas of concern include hydrologic and chemical aspects and erosion (fig. 2). The overall impact might be a decline in streamflow, an increase in dissolved solids in stream water, and a reduction in erosion.

We can suggest ways to study and quantify these impacts on streamflow. But the fact remains that our basic knowledge of what actually happens to streamflow when a forest is fertilized is pretty meager.

Figure 2.—Potential impact of forest fertilization on streamflow. Little quantitative information is available for the various changes listed within the blocks.



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QUANTITY AND QUALITY OF STREAMFLOW AFTER UREA FERTILIZATION ON A FORESTED WATERSHED: FIRST-YEAR RESULTS

by G. M. AUBERTIN, D. W. SMITH, and J. H. PATRIC.

Aubertin and Patric are respectively Research Soil Scientist and Forest Hydrologist, USDA Forest Service, Northeastern Forest Experiment Station, Timber and Watershed Laboratory, Parsons, W. Va. Smith, Assistant Professor of Forestry at Virginia Polytechnic Institute and State University, Blacksburg, Va., was formerly Chairman, Department of Forest Technology, Glendale State College, Glendale, W. Va.

ABSTRACT. Streamflow was analyzed to determine the effects on the quantity and quality of water flowing from a 74-acre calibrated watershed that had been fertilized with 500 pounds of urea per acre. During the first year after fertilization, no change was detected in the quantity of streamflow. Water quality, as determined from analysis of 829 samples, remained high. Comparison of nitrogen discharge data for the year before and after fertilization revealed approximately 18 percent greater nitrogen discharge after fertilization. Loss of nitrogen was accompanied by increased loss of certain metallic cations.

WE ARE FACED with a dilemma. A substantial amount of our productive forest land is lost annually to highways, airports, impoundments, recreational areas, wilderness reserves, shopping centers, home sites, and agriculture; yet our increasing population demands more wood. Correcting one or more of the conditions that limit tree growth may help resolve our dilemma.

It is known from agronomic research that insufficient soil N will limit plant growth. Therefore it has been proposed that forest fertilization, with N, will in-

crease tree growth. Though the application of N fertilizer may increase growth, its widespread use cannot be recommended until its effects on the environment have been determined.

A pilot study was designed and is being conducted on the Fernow Experimental Forest near Parsons, West Virginia, to evaluate effects of fertilizing a forested watershed with urea. The specific objective of this pilot study is to determine how applications of a relatively large amount of soluble N (230 pounds per acre) as urea to a young hardwood

stand would affect the quantity and quality of streamflow from the watershed. This paper presents the first-year results of this study.

EXPERIMENTAL AREAS AND PROCEDURES

The study area is a 74-acre east-facing watershed from which all marketable trees were cut in 1957-58. The average slope is 40 percent, with a range of 14 to 65 percent. The watershed now supports a dense stand of vigorously growing sprouts and seedlings as well as some advance growth and cull residuals from the clearcutting. Dominant species are oaks (*Quercus* spp.), yellow-poplar (*Liriodendron tulipifera* L.), basswood (*Tilia americana* L.), maples (*Acer* spp.), American beech (*Fagus grandifolia* Ehrh.), and black cherry (*Prunus serotina* Ehrh.). The stand averages about 30 feet in height and has a basal area of 43 square feet per acre (in trees greater than 5 inches d.b.h.). Understory vegetation is typical of Appalachian hardwood forests.

The soil, mapped as Calvin channery silt loam, is derived from sandstone and acid red shale of the Hampshire (formerly Catskill) geologic formation. It is a member of the loamy-skeletal mixed mesic family of Typic Dystrocrepts. Soil depth ranges from 2 to 5 feet, with an average depth of 32 inches.

The nearby control watershed has remained undisturbed since a clearcutting about 1905-10. It has and will continue to be closely monitored for quantity and quality of streamflow. Soil type and stream discharge (as percentage of precipitation) are practically the same as on the experimental watershed.

Fertilization was begun at 4:30 p.m. 14 May 1971 and ended about noon the following day. Five hundred pounds per acre of urea (230 pounds of N per acre) were applied by helicopter. (Urea was provided by the Agrico Chemical Com-

pany of Memphis, Tennessee.) The helicopter flew about 100 feet above the tree tops and distributed prilled urea in swaths about 50 to 60 feet wide. No attempt was made to avoid the stream channel, because the perennial channel area was small (estimated to occupy only 0.03 percent of the watershed) and the intermittent portions of the channel were not flowing at the time of application. Uniformity of distribution was checked with 312 open containers distributed over 52 randomly located sampling plots.

A 4-acre area, located near the watershed's western ridge, was left unfertilized to provide within-watershed comparison plots.

Soil and bud samples were obtained from fertilized and unfertilized plots before fertilization and 1 year later in an attempt to provide supplemental information about the effect of urea fertilization on the environment.

Water-yield data and some water-quality data (specific conductance, total alkalinity, pH, and turbidity) extend back to 1951. Concentrations of Ca, Mg, Na, K, Zn, Cu, Mn, Fe, sulfate, total phosphate, ammonium-N, and nitrate-N in the stream have been recorded since July 1969.

Specific conductance, pH, and turbidity were determined with a specific conductance Solu bridge, a Hellige comparator, and a Hach model 1860 laboratory turbidimeter, respectively. Alkalinity was determined by the methyl orange titration method. Ca, Mg, Na, and K determinations were made on 20-ml. samples containing 2 ml. of 1-percent Lanthanum in 5-percent HCl solution, using a Perkin-Elmer model 290B atomic absorption spectrophotometer connected to a Texas recorder. Zn, Cu, and Mn determinations were made on concentrated samples (concentrated by boiling down to one-tenth original volume), using the same instruments and procedures as above. Sulfates, Fe, total phosphate, ammonium-N, and nitrate-N determinations

were made according to Hach's: SulfaVer III, FerroVer, PhosVer III, Nessler's, and NitraVer IV methods respectively.

(The use of trade, firm, or corporation names is for information only and should not be considered an endorsement by the Forest Service or the U.S. Department of Agriculture.)

During application and for 66 hours thereafter, 300-ml. water samples were obtained from the fertilized watershed at 15-minute intervals. However, when the helicopter spread urea directly over the lower portion of the stream channel, and during stream rise after spring showers, samples were taken every 2 minutes. In addition, every 6 hours throughout this period, quart-size water samples were obtained from both the fertilized and control watersheds. The 300-ml. samples were collected in glass bottles having pressure-type stoppers. Once filled and sealed, these bottles contained no air bubbles. The quart-size samples were collected in polypropylene bottles.

Samples were taken to the laboratory as soon as possible and placed in a refrigerator maintained at 34°F. Most ammonium-N and nitrate-N analyses were completed within 24 hours after collection. All analyses were completed within 7 days of sampling. In general, only ammonium-N and nitrate-N determinations were made on the 300-ml. samples, and all 16 analyses were made on the larger samples.

During the 30 days after urea application, 463 water samples were collected and analyzed from the fertilized watershed. A total of 643 samples were analyzed during the 1971 growing season and 186 samples during the dormant season. Sampling frequency of at least one per day, and as frequently as one every minute during rapid stream rise, lasted through the end of June. From June through mid-September streamflow was frequently too low for sampling.

RESULTS

Actual rate of urea distribution varied between 400 and 600 pounds per acre, with no evidence of "skips" (all open containers received some urea). Highest rates of application occurred on the upper slopes; application in the channel vicinity tended to be near or below the planned rate of 500 pounds per acre.

Flow-prediction analyses of stream discharge revealed no detectable change in water yield during the first year after urea fertilization.

Rainfall during April and June 1971 was substantially below normal (table 1). During the first 165 days after fertilization, what rain did fall generally fell as light showers, and on only 23 days did rainfall exceed $\frac{1}{4}$ inch. As a result, mean daily stream discharge from the fertilized watershed was very low during June, July, August, and early September (fig. 1). Mean daily stream discharge from the control watershed was similar.

The soil and bud analysis (tables 2 and 3) provided cursory information relating to the initial effect of urea fertilization on the nutrient balance of soil and plants. Additional data will be collected before an interpretation of the data is attempted.

Ammonium-N and nitrate-N concentrations in the stream, for the 72 hour period commencing with the start of urea application, are shown in figure 2. The increases in ammonium-N concentration coincident with application can be seen. Within the first 24 hours, the ammonium-N concentration in the stream increased from a prefertilization level of about 0.15 p.p.m. up to about 0.8 p.p.m. This level was maintained for the next 19 hours, followed by a gradual decline to near prefertilization level by the end of the first week. Except for storm influences (to be discussed later) the ammonium-N concentration has since remained rather consistent at or below 0.2 p.p.m.

Nitrate-N increased gradually from a

Table 1.—Precipitation and stream discharge for the fertilized watershed

Month	Prefertilization (1970-71)			Postfertilization (1971-72)			20-year average (1952-71)		
	Ppt.	Stream discharge		Ppt.	Stream discharge		Ppt.	Stream discharge	
	Inches	Inches	% of ppt	Inches	Inches	% of ppt	Inches	Inches	% of ppt
May	2.31	0.41	17.7	5.51	2.62	47.5	4.88	2.21	45.3
June	4.71	.18	3.8	2.85	.19	6.7	5.30	.96	18.1
July	7.37	.50	6.8	4.27	.05	1.2	5.44	.77	14.2
August	4.66	.20	4.3	5.35	.19	3.6	4.99	.89	17.8
September	4.63	.26	5.6	7.42	1.54	20.8	3.63	.82	22.6
October	2.44	.09	3.7	2.55	.30	11.8	3.50	.62	17.7
Growing-season total	26.12	1.65	6.3	27.95	4.88	17.5	27.77	6.28	22.6
November	3.58	1.13	31.6	4.84	1.56	32.2	3.72	0.96	25.8
December	8.33	4.50	54.0	2.75	2.48	90.2	5.11	2.45	47.9
January	5.90	4.33	73.4	6.85	4.30	62.8	5.01	3.07	61.3
February	4.48	4.10	91.5	7.92	4.91	62.0	4.54	2.89	63.7
March	4.76	3.05	64.1	4.58	4.06	88.6	5.85	3.97	67.9
April	1.78	.91	51.1	6.89	4.67	67.8	5.19	2.95	56.8
Dormant-season total	28.83	18.01	62.5	33.83	21.98	65.0	29.44	16.28	55.3
Water-year total	54.95	19.66	35.8	61.78	26.86	43.5	57.21	22.56	39.4

Figure 1.—Mean daily stream discharge (cubic feet per second per square mile) from the fertilized watershed for the 1971 growing season and 1971-72 dormant season. Arrow indicates application of urea fertilizer.

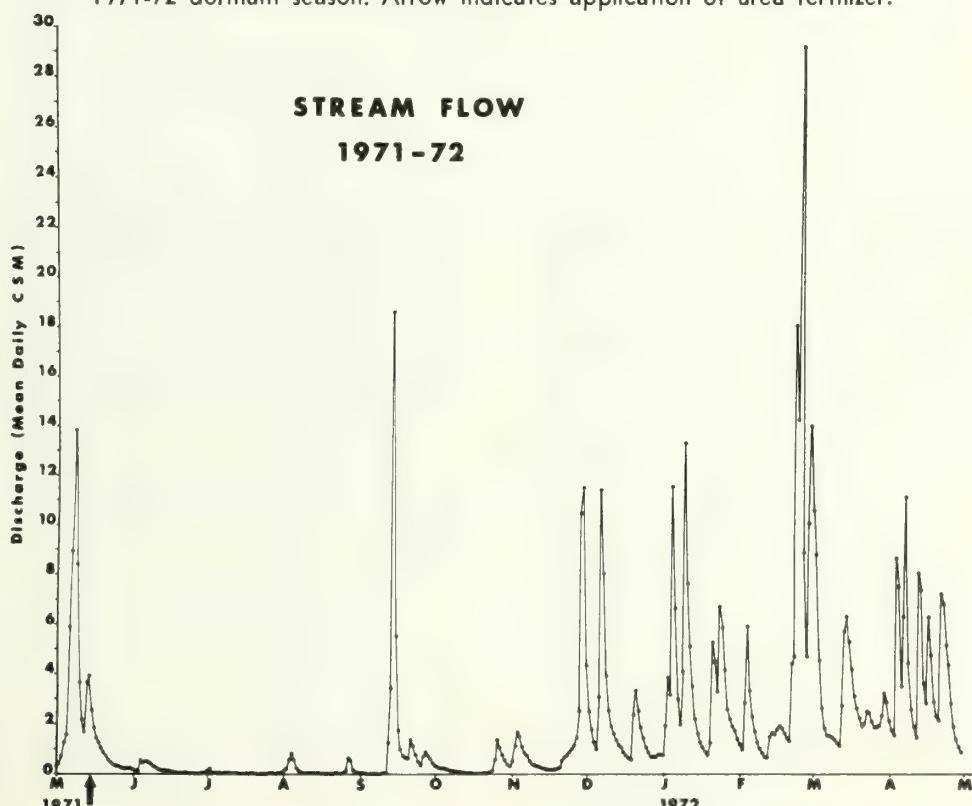


Table 2.—Mean values of soil analyses¹

Item	0 - 2-inch depth						2 - 10-inch depth					
	Fertilized			Unfertilized			Fertilized			Unfertilized		
	Before	After	Difference	Before	After	Difference	Before	After	Difference	Before	After	Difference
pH	5.0	4.8	-0.2*	4.5	4.8	+0.3**	4.7	4.7	0	4.7	4.6	-0.1
Nitrogen (percent)	.61	.48	-.13**	.57	.44	-.13	.22	.18	-.04**	.25	.15	-.10*
Phosphorus	101	70	-31**	99	51	-48*	37	22	-15**	24	15	-9*
Potassium	331	247	-84**	200	218	+18*	151	158	+7	118	150	+32*
Calcium	2,324	1,500	-824**	883	608	-275*	837	665	-172**	333	300	-33
Magnesium	311	195	-116**	212	153	-59	101	84	-17**	63	42	-21

^{*}"t" test significant at 5% probability level.^{**}"t" test significant at 1% probability level.¹Analyses done by courtesy of Agrico Chemical Company, Agronomic Service Laboratory, Washington Courthouse, Ohio.Table 3.—Mean values of bud nutrient analyses¹

Element	Yellow poplar						Sugar maple						American beech		
	Fertilized			Unfertilized			Fertilized			Unfertilized			Fertilized		
	Before	After	Difference	Before	After	Difference	Before	After	Difference	Before	After	Difference	Before	After	Difference
Nitrogen	2.33	2.55	+0.22**	2.20	2.27	+0.07	1.80	2.03	+0.23**	1.68	1.82	+0.14*	—	—	—
Phosphorus	.20	.22	.02**	.19	.18	-.01	.18	.16	-.02**	.19	.17	-.02*	—	—	—
Potassium	.51	.66	.15	.51	.57	.06*	.32	.45	.13**	.24	.32	.08*	—	—	—
Calcium	.95	.88	-.07**	1.00	.88	-.12	2.45	1.92	-.53**	1.01	.86	-.15	—	—	—
Magnesium	.43	.38	-.05**	.40	.35	-.05*	.27	.25	-.02*	.27	.23	-.04*	—	—	—

^{*}"t" test significant at 5% probability level.^{**}"t" test significant at 1% probability level.¹Analyses done by courtesy of Agrico Chemical Company, Washington Courthouse, Ohio.

IMMEDIATE EFFECTS

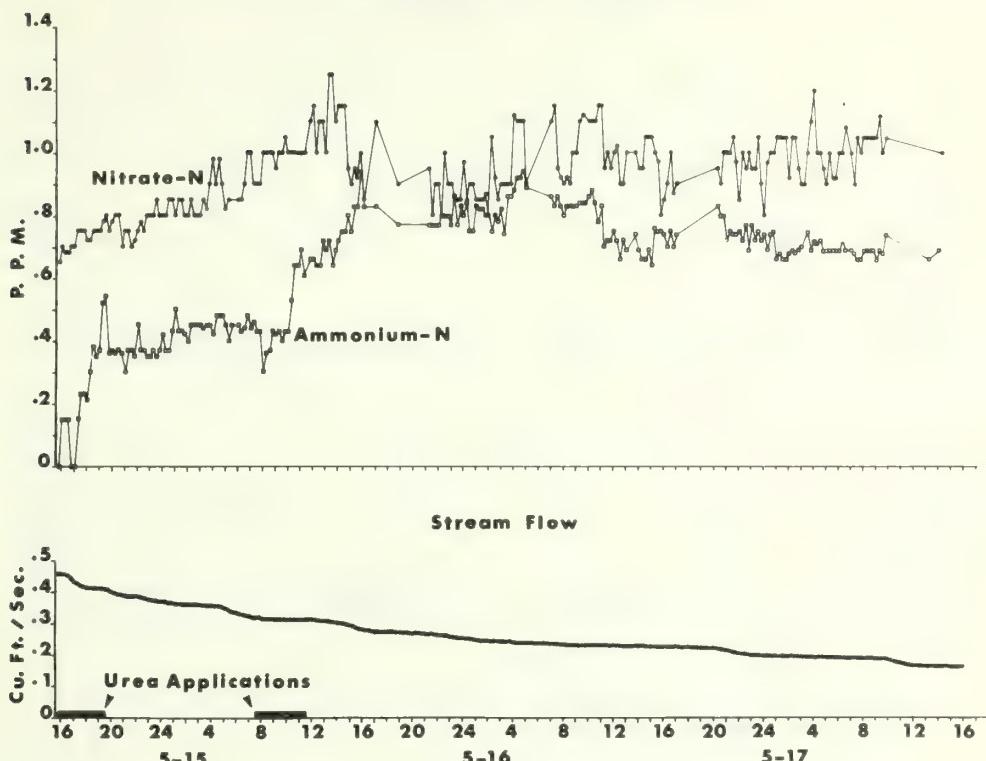


Figure 2.—Ammonium- and nitrate-nitrogen concentrations in the stream of the fertilized watershed during and immediately after urea application.

prefertilization level of about 0.7 p.p.m. up to approximately 1 p.p.m. within 24 hours. No relationship between periods of urea application and nitrate-N concentrations in the stream was observed. The nitrate-N level remained at approximately 1 p.p.m. for an additional 48 hours, then increased to approximately 2 p.p.m.

Both ammonium-N and nitrate-N concentrations were influenced by storms. Figure 3 shows the influence of a rather intense storm on June 4. Data from this storm, and several others, indicated a sharp increase in the stream's ammonium-N concentration coincident with the onset of rainfall. Usually maximum ammonium-N concentration occurred during the early part of the storm and before peak stream discharge. It then declined

to near and sometimes below prestorm level, even though rainfall continued and stream discharge remained high.

Nitrate-N concentrations likewise showed a sharp increase associated with rainfall. However, maximum nitrate-N concentrations usually occurred later, proportionately greater increases took place, higher levels were maintained longer, and decline was more gradual than for ammonium-N.

These same conditions appear to have existed before fertilization, although our prefertilization sampling intensity was insufficient for drawing a firm conclusion.

The highest daily nitrate-N concentrations found in the stream for the growing and dormant seasons before and after urea fertilization are shown in figure 4. Except for storm influences on 4 June,

STORM EFFECTS

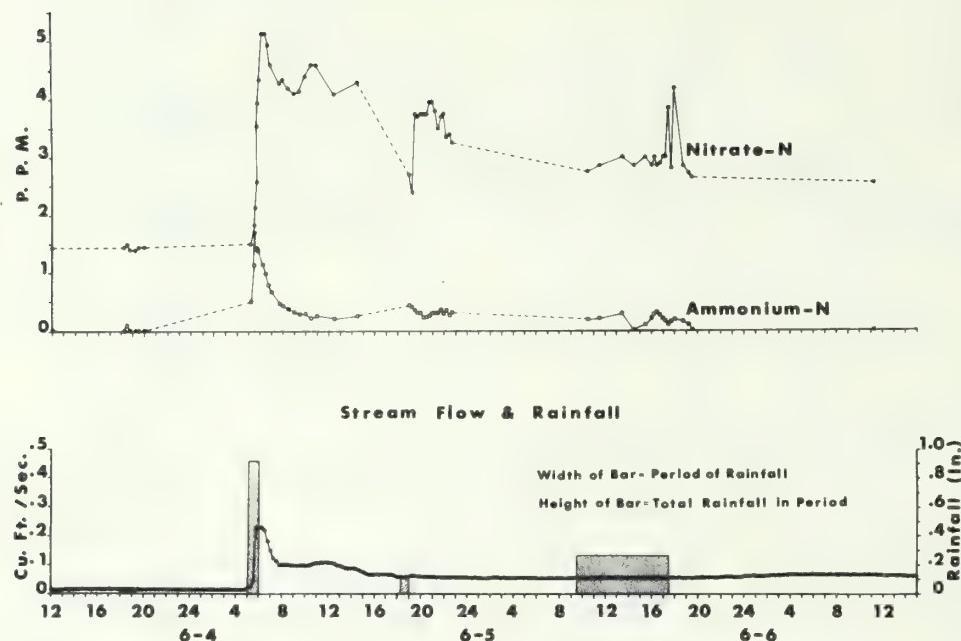


Figure 3.—Relationship between ammonium- and nitrate-nitrogen concentrations and rainfall and streamflow.

the nitrate-N level gradually decreased throughout June to approximately 1 p.p.m. or almost to the prefertilization level. At this point, dry weather and summer storms influenced the conditions. Rainfall for June through early September was below normal, and although some flow continued in the gravel of the stream channel, it was frequently too low for sample collection. As a result, there are gaps in our data during an important part of the growing season, and interpretation of the data after flow-producing storms is complicated.

The relationship between nitrate-N concentration and stream discharge is apparent when one compares figures 1 and 4. Between May 1971 and March 1972, high storm-produced stream discharges were accompanied by above-average nitrate-N concentrations. Average post-fertilization nitrate-N concentrations appear to be about 5.0 to 5.5 p.p.m.

(about 7 times prefertilization levels). High nitrate-N concentrations were not associated with high storm-produced stream discharge during March and April 1972. The data suggest that nitrate-N outflow has been declining since the first of March despite substantial stream discharge.

The highest nitrate-N concentrations were generated during June through mid-September (fig. 4) by flow-producing storms that followed dry periods in which little or no stream discharge occurred. Maximum nitrate-N concentration and discharge occurred in mid-September. A prolonged dry period occurred before 12 September; surface streamflow was nonexistent—then came 4.6 inches of rain within 48 hours. The concentrated soil solution, high in nitrate, was flushed from the soil; and nitrate-N concentration for this storm was 14.1 p.p.m.

NITRATE-N CONCENTRATION*

★ (Highest Daily Value)

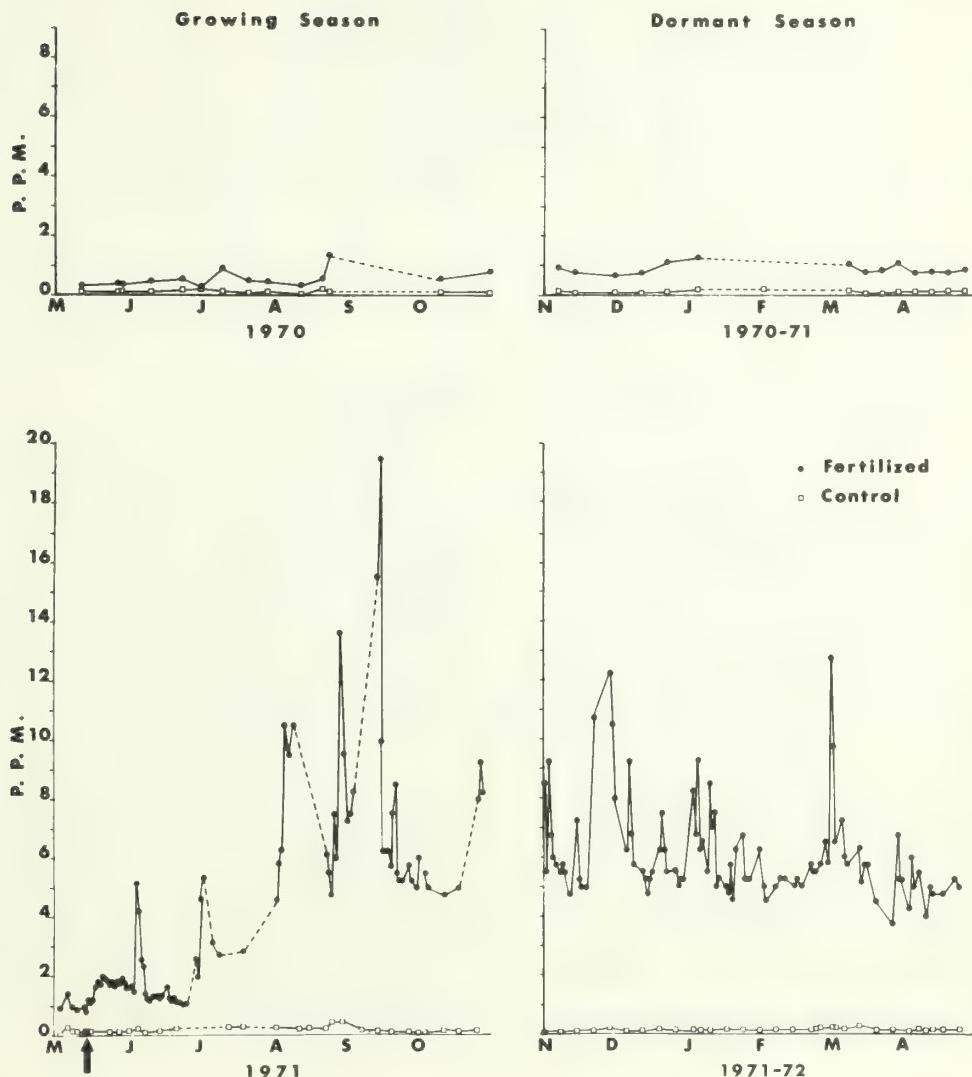


Figure 4.—Highest daily nitrate-nitrogen concentrations in the stream from the fertilized and control watersheds before and after fertilization. Arrow indicates time of application of urea fertilizer.

The first part of the storm occurred between 6:00 p.m. 12 September and 6:00 a.m. 13 September, and 2.3 inches of rain fell. Peak stream discharge of 0.73 cubic feet per second and maximum nitrate-N concentration of 17.1 p.p.m. occurred about midnight 12 September.

The nitrate-N concentration dropped to 12.2 p.p.m. by noon 13 September. Throughout the day, sporadic light showers maintained stream discharge, while the nitrate-N concentration averaged about 13 p.p.m. The second part of the storm occurred between midnight 13

September and 4:00 p.m. 14 September, with 2.1 inches of rainfall. Nitrate-N concentration increased gradually to 14.5 p.p.m. at 6:30 a.m., then jumped to 19.8 p.p.m. at 6:35 a.m.; decrease was rapid, and by the end of the storm the concentration had returned to 13.0 p.p.m. Peak stream discharge of 5.11 cubic feet per second also occurred at 6:35 a.m.

This combination of high nitrate-N concentration and high stream discharge accounted for 73 percent of the nitrate-N discharged from the watershed during the 1971 growing season (4.8 pounds per acre of nitrate-N were discharged during the week of 12-19 September 1971). After this flushing, the nitrate-N concentration dropped to about 5.5 p.p.m.—signaling the beginning of a definite trend where the nitrate-N concentrations stabilized around 5.5 p.p.m. while stream discharge increased.

A tenfold increase in nitrate-N discharge occurred during the first growing and dormant season after fertilization (table 4). If one considers the increased loss of N as coming entirely from the urea fertilizer, then 17.8 percent of the applied N was discharged from the watershed during the first year after fertilization (2.4 percent during the growing season and 15.4 percent during the dormant season). This does not include possible losses as urea, through volatilization, or in various organic forms.

The dissolved substances in the streams from the fertilized and control watersheds are quantified in table 5. Averages presented are simple averages (concentrations divided by the number of samples). The average concentration of dissolved solids in the fertilized watershed's stream increased 110 percent during the year after fertilization. The increase in the concentration of dissolved solids was accompanied by increases in the concentrations of nitrate-N, Ca, Mg, Na, K, Cu, and Zn; it was also accompanied by decreases in the concentrations of total phosphate, Fe, sulfate, Mn, and ammonium-N.

It should be pointed out and emphasized that the changes in composition noted in the stream from the fertilized watershed are not all due to the urea application. Increases in concentrations of Ca, Mg, K, Cu, Zn, and nitrate-N, and decreases in Fe, total phosphate, and Mn concentrations were also noted in the stream from the control watershed. Concentrations of ammonium-N, sulfate, and Na in the streams from the control and fertilized watersheds exhibited opposite changes (table 5).

It also should be pointed out and emphasized that, in general, what changes did occur were relatively small and inconsequential in terms of permissible levels for public drinking water.

Table 4.—Pounds per acre of ammonium- and nitrate-nitrogen discharged from the experimental watershed before and after urea fertilization

Year	Ammonium-N	Nitrate-N
1970 growing season	0.6	0.8
1970-71 dormant season	.7	3.9
Total, year before fertilization	1.3	4.7
1971 growing season	0.2	6.6
1971-72 dormant season	.5	38.4
Total, year after fertilization	0.7	45.0

Table 5.—Average concentrations of dissolved substances in streams before and after urea fertilization
[In p.p.m.]

Dissolved substance	Growing season				Dormant season				Full year ²			
	1970		1971		1970-71		1971-72		1970-71		1971-72	
	Fertilized	Control	Fertilized	Control	Fertilized	Control	Fertilized	Control	Fertilized	Control	Fertilized	Control
Dissolved solids ¹	31	13	60	13	.27	.12	.60	.12	.29	.12	.60	.12
Nitrate-N	0.55	0.11	3.91	0.26	0.95	0.10	5.79	0.13	0.76	0.10	4.86	0.21
Ammonium-N	.45	.36	.16	.23	.15	.13	.10	.14	.23	.19	.13	.20
Phosphate (total)	.044	.038	.019	.008	.029	.020	.008	.006	.036	.029	.014	.007
Potassium	1.00	.73	1.42	.63	.74	.52	1.33	.63	.86	.62	1.39	.63
Calcium	3.24	1.07	4.94	1.22	2.00	.71	8.12	1.17	2.58	.88	6.36	1.20
Magnesium	1.32	.52	1.46	.46	.88	.35	2.10	.41	1.09	.43	1.69	.44
Sodium	.97	.66	1.17	.46	.86	.48	1.18	.43	.91	.56	1.17	.45
Sulfate	6.8	3.4	5.3	3.3	5.8	3.0	4.4	3.4	6.4	3.2	4.8	3.4
Iron	.14	.16	.07	.06	.23	.07	.08	.08	.18	.11	.07	.07
Copper	.015	.012	.030	.026	.016	.012	.029	.024	.015	.012	.029	.025
Manganese	.015	.015	.009	.009	.017	.014	.003	.003	.016	.014	.006	.006
Zinc	.029	.025	.069	.069	.030	.035	.052	.091	.029	.029	.060	.091

¹Estimated from specific-conductance measurements (dissolved solids = 0.70 X specific conductance).

²Average of all values obtained between 1 May 1971 and 30 April 1972.

DISCUSSION

Urea application was completed within 20 hours with relatively uniform distribution over the watershed. Since no attempt was made to avoid the small perennial stream, some urea fell directly into the stream. Estimates, based on the area of the stream and average application rate, indicate that 11 pounds of urea (equal to 5 pounds of nitrogen) probably fell into the stream and presumably left the watershed as dissolved urea, ammonia, or nitrate.

The amount of N lost through ammonia volatilization is open to question. A light intermittent rain began within 10 hours after application. This rain (only 0.30 inch in 24 hours) dissolved the urea on the foliage and litter; but due to the duration of the rain and its low intensity, it is doubtful if much of the dissolved urea moved into the mineral soil. Little, if any, was flushed into the stream, because stream discharge continued to decline throughout the period. Most of the dissolved urea probably was absorbed in the microbiologically active organic layers.

No rain fell for the next 12 days and, as the litter layer dried and ammonification took place, some N was lost from the watershed through volatilization; an ammonia odor could be detected in the atmosphere within 60 hours of application. This odor was noticeable for about 1 week. Additional N probably was lost to the atmosphere through the decomposition of understory vegetation killed by localized excess urea. This decomposing organic material also provided a source of mineralizable N.

The question of how much of the applied N left the watershed in the organic form cannot be answered. However, with low stream discharge and the fact that a limited number of determinations made before application showed almost no organic N in the stream, we feel that little of the applied N was discharged from the watershed in organic form.

The definite increase in ammonium-N content coincident with periods of urea application (fig. 2) raises several questions, because it is an established principle of soil science that ammonia is held rather tightly by the exchange complex. The fact that a definite increase occurred cannot be questioned because more than 200 samples were collected and analyzed during the period and a plot of values shows a definite and well-defined increase associated with periods of urea application (fig. 2).

It is proposed that the increased ammonium-N, which occurred during urea application, resulted from urease conversion of the urea that fell into the stream. Stream pH was 6.2 throughout the period. Although our method for determining ammonium-N does not measure urea dissolved in distilled water, an equal amount of urea added to a stream-water sample will, within a short period of time, produce a marked increase in the ammonium-N concentration.

The reason why it required about 1 week for the ammonium-N concentration to return to prefertilization level is not clear. It is doubtful that any urea that fell into the water could persist for a week. Therefore, it is proposed that some of the urea that fell on the moist stream-side soil moved through the acid soil (pH 4.7 to 5.0) and into the stream as dissolved urea. Once in the stream it was converted into ammonium.

Actually, the immediate effects of urea fertilization on water quality were small and short-lived (fig. 2 and 4). Except for storm influences, ammonium-N and nitrate-N concentrations had returned to prefertilization levels by 1 June and 1 July, respectively.

During this time, streamflow decreased to a trickle, a condition maintained to mid-September. As a result, the only samples that could be obtained were associated with flow-producing storms. This biased our data to the higher-than-normal ammonium-N and nitrate-N con-

centrations found to be associated with storms. Although this accentuated the ammonium-N and nitrate-N concentrations generally, the small volume of discharge precluded large amounts of N being discharged from the watershed.

The data indicate that during the first growing season after urea fertilization, the amount of N discharged from the watershed was small (table 4) and almost entirely storm-related. We hypothesize that the storm-related increase in ammonium-N came with the rain or was washed from streamside vegetation, while the increased nitrate-N came from the solution flushed out by the rain. Probably the increased nitrate-N in the soil solution did not come entirely from the fertilizer, because urea is known to stimulate dissolution of humus fractions and mineralization of organic N.

The onset of fall rains, accompanied by decreased transpiration and nutrient uptake associated with leaf fall and plant dormancy, brought increased streamflow. Ammonium-N concentration stabilized at slightly less than 0.2 p.p.m. while nitrate-N concentration averaged about 5.5 p.p.m. The combination of relatively high streamflow and relatively high nitrate concentration resulted in a substantial amount of N being discharged from the watershed during the fall and winter months.

The relatively high nitrate-N concentration during the fall and early winter months may have been due, in part, to release of N taken up by the vegetation during the growing season. Leaf-fall was early, and the temperature was generally mild through the first of the year.

These data suggest the possibility of an interaction between urea fertilization and the discharge of metallic cations. The specific conductance, which is a measure of the ionic activity in the stream, about doubled during the first growing season after urea fertilization and was almost 2 $\frac{1}{4}$ times greater during the dormant season (table 5). This re-

flected the greater concentration of certain metallic cations that accompanied the expected increase in nitrate-N outflow. Although the reason for the increase in cation concentration is not fully understood, it is reasonable to expect increased cation discharge to accompany increased nitrate discharge, since soil bases are known to move as nitrates in noncalcareous soils. Also, the added N probably increased the microbial activity and decomposition of the organic substrate, resulting in greater nutrient release and discharge.

The inconclusive results from our soil analyses point out the fact that the application of 500 pounds of urea per acre of forested watershed did not produce any major change that could be interpreted as being detrimental to the environment. It is probable that weather conditions affected the nutrient status of the soil more than the urea application did.

Pre- and postfertilization soil samples were taken during April 1971 and 1972 respectively. Rainfall for February through April of the prefertilization year was 29 percent less than the 20-year average. For the same 3 months of the postfertilization year, rainfall was 24 percent greater than the 20-year average. The difference in rainfall amounted to 8.37 inches. It is proposed that this marked difference in precipitation had a strong influence on the biologic and chemical transformation of N and other nutrients in the soil.

It is likely that, had we analyzed the organic layers, we could have accounted for a much larger portion of the applied N. We know that the light rain immediately after application dissolved the urea on the foliage and litter and probably only moved it into the biologically active organic layers. There the applied N presumably became microbiologically tied up in the soils' organic substrate. If, as postulated, a substantial portion of the applied N has become tied up in the or-

ganic substrate, it will be released in time.

It is also reasonable to assume that a portion of the applied N has been leached through the soil profile to below sampling depth. Most of this N will eventually be accounted for, either as N taken up by the plants or as nitrate-N flushed into the streams by soil water displacement.

The increased N content of the buds formed after fertilization was expected, and it supports our hypothesis that a substantial portion of the applied N would enter the ecosystem and be recycled. How this higher N content will influence the physiological activity of the trees during the second and subsequent growing seasons remains to be seen.

Basic to any water-quality study is the relationship between substances in the water and standards indicating the suitability of water for specific uses. The U.S. Public Health Service Drinking Water Standards are usually considered the standards of acceptance:

	Mg./L.
Copper	1.0
Iron	.3
Manganese	.05
Nitrate-N	10.0
Sulfate	250.0
Total dissolved solids	500.0
Zinc	5.0

Our average concentrations of dissolved substances (table 5) are all well below the Public Health limit. Concentrations of nitrate-N, the substance of major concern, were below Public Health limits 811 times out of the 829 samples analyzed. Of the 18 samples that exceeded the limit, 8 came from the storm of 12 September. All the high nitrate samples were associated with a flushing out of the soil solution.

Although the nitrate-N discharge from the fertilized watershed increased, as expected, during the first year after fertilization, this increase should not cause alarm. It should be obvious that only an

infinitesimal part of the drainage basin's discharge came from the 74-acre fertilized watershed, and the slight increase of nitrate-N concentrations in the fertilized watershed's stream was diluted to obliteration as soon as this feeder stream flowed into the main channel.

The results of this study should, however, alert forest managers to the potential for water-quality impairment whenever large amounts of fertilizer are applied to large portions of a drainage basin.

The substantial amount of nutrients discharged during the first year after urea fertilization raises several major questions. Where did all the nutrients come from? Did all parts of the watershed lose nutrients equally, or did one area of the watershed contribute more than other areas? What would have been the results had an unfertilized buffer strip, say 1 chain wide, been left along each side of the channel? Would lower application rate substantially reduce the nutrient loss? And what about the form in which N was applied? Would a less soluble or a slow-release form have significantly reduced our first-year loss?

The answers to these questions cannot be found in this study. The main objective of this pilot study was to determine how the application of a relatively large amount of a readily available N fertilizer to a young hardwood stand would affect the quantity and quality of streamflow from the watershed. First-year results show that quantity of streamflow was unaffected, but a substantial amount of nitrogen was lost from the watershed. This loss of N was accompanied by increased loss of certain metallic cations. We can only speculate as to the mechanisms that caused these responses and as to what the results would be under different experimental conditions. Answers to the questions raised must await further research.

ENVIRONMENTAL ASPECTS OF SEWAGE-DERIVED FERTILIZERS

by J. D. GAGNON, *Canadian Forestry Service,
Environment Canada, PO. Box 3800, Ste. Foy,
Quebec 10, Quebec.*

ABSTRACT. A 10-year-old white spruce (*Picea glauca* (Moench) Voss) plantation established on sandy soil gave a 30-percent height-growth response over control trees 4 years after application of 500 pounds per acre of sewage sludge. This result is a challenge to foresters to turn what has always been a liability into a commercial asset without contributing to water pollution.

AS THE HUMAN population increases, so does the problem of disposing of sewage sludge, produced at approximately 50 pounds of dried matter yearly per person. In Canada, excluding Quebec province, 80 percent of the sewage sludge is discharged into lakes or rivers; the remainder is either incinerated or trucked to land-fill areas, or is lagooned. In Quebec, sewage sludge disposal has not changed since early colonization. Most of the 150,000 tons of sewage sludge produced annually is discharged into watercourses that flow into the St. Lawrence River, transforming the river into a huge sewer. Only a nominal portion of the sludge (less than 1 percent) is treated and given to farmers.

The water-pollution situation in Quebec is alarming, to such a degree that from Montreal to Quebec City pollution of the St. Lawrence River is a recognized fact. And from Quebec City toward the

Gulf of St. Lawrence the ecological equilibrium of the river is seriously jeopardized. It is this kind of water that has to be pumped through purification installations and transformed into potable supplies for human and other uses. The consumer has no choice but to drink water that tastes of chlorine, sulphureous gas, or other prophylactic additions.

Although it is true that rivers can assimilate great quantities of sewage sludge, it should not be forgotten that there are limits to self-purification and biodegradation. Moreover, these limits are often markedly lowered by the continuous addition of industrial waste, so that the margin of safety becomes dangerously narrow. In a society constantly calling for economic controls, we foolishly contaminate a vital commodity and wonder why millions of dollars are required to purify it. The answer is obvious: stop dumping sewage sludge into waters and

Table I.—Lower and upper limits of sewage-sludge physico-chemical properties compared with forest humus and farmyard manure

Item	pH	Water retention (%)	Organic matter (%)	C		Ca	Mg	K	P
				N	N (%)				
Sewage sludge	5.2-5.9	150-200	30-56	15-16	1.1-1.9	4,800-22,000	840-2,000	920-2,200	1,200-1,960
Forest humus	4.3-4.7	300-500	85-95	31-39	1.1-1.5	1,600-3,800	4,800-6,000	1,000-1,800	950-1,400
Farmyard manure	7.6-8.8	75-95	85-97	30-43	1.2-1.6	1,200-37,000	800-2,800	10,000-15,000	2,900-3,700

Note: These data are from 10 to 15 samples.

find a substitute for its disposal. For ecologists, the best means is to submit sewage sludge to secondary treatment and to urge that research be directed toward the more widespread utilization of treated sludge.

It was with this purpose in mind that it was decided to test the use of sludge in forestry. A study was undertaken at Grand'Mère plantations, using white spruce as the test tree. Results obtained after 4 years are sufficiently conclusive for the writer to believe that treated sewage sludge is a promising fertilizer for tree growth, especially for white spruce planted on sandy soils.

For greater appreciation of the value of sewage sludge as a growth stimulator, its physico-chemical properties have been compared (table 1) with forest humus layer (H layer) of medium quality and with farmyard manure. Used in another part of the study area in 1920, manure has already shown (*Gagnon and Boudoux 1968*) that it is well able to enhance the growth of white spruce.

MATERIALS AND METHOD

The sewage sludge used in this study was obtained from the waterpurification installation at Valcartier military camp, some 15 miles northwest of Quebec City. Sludge, at this plant, is submitted to a primary treatment, which consists of a mechanical process grinding solids such as sticks and rags. After grinding, the material is sent to three grit chambers where smaller solids, such as soil particles, sand, and stones settle at the bottom of the chamber.

The sludge is then directed into two 50,000-gallon tanks through which water slowly passes, allowing suspended particles to sink to the bottom. After being chlorinated to kill harmful bacteria, the water is discharged into the Jacques Cartier river by pipe, and the solids are pumped into digestion tanks, heated to 90°F. to destroy pathogenic bacteria,

and submitted to anaerobic decomposition for 3 months. During this last process, lime is added to the sludge to facilitate filtration and to raise its pH. The treated sludge is then pumped to sanddrying beds.

This material, called digested sewage sludge, was used for the experiment reported in this study. As it was only partially dried on filter beds, it was hauled to open fields and air-dried in piles for several days; occasionally it was turned over to permit aeration and avoid overheating. After being air-dried, the sludge was passed through a $\frac{1}{4}$ -inch sieve and bagged. Samples of the bagged material were collected and prepared for laboratory work. Physico-chemical properties were determined, using conventional analytical methods. These properties were compared with forest humus (H layer) and farmyard manure (table 1).

Sample trees were selected from a slow-growing white spruce plantation, planted in 1958 on a terrace along the St. Maurice River near Grand'Mère, Quebec. The soil, composed of old marine sand deposits lacking organic matter, was excessively drained and covered with a carpet of *Polytrichum commune* (Hedw.). The mineral nutrient content of the first 8 inches (20 cm.) of surface soil was very low. June, July, and August rainfall recorded during 11 years (1961–71) varied from 6 to 14 inches (15 to 35 cm.). For the same period the monthly mean minimum temperature varied from 50° to 60° F. and the mean maximum from 70° to 80° F.

One acre of the planted area was divided into 25 blocks, 25 trees in each. Five blocks were selected at random, and the heights of 5 trees within each block, also selected at random, were measured with a graduated pole; the 25 trees were kept as control trees. Among the 20 remaining blocks, another 5 blocks, each containing 5 trees with a height to the nearest 1/10 foot (3 cm.) corresponding to the 25 control trees, were retained for

fertilization. Thus 25 control trees were paired with 25 trees to be fertilized. The purpose of pairing trees was to remove a source of variation and increase precision. Sewage sludge was applied to the soil at 500 pounds per acre (560 kg./ha.).

In 1965 and 1966 autumn height measurements, made at internodes, were subjected to a two-tailed "t" test. After the addition of sludge, a one-tailed "t" test was used to determine if difference between control and treatment was significant.

RESULTS AND DISCUSSION

The addition of lime after primary sedimentation at the sewage-treatment plant contributed to raise the pH from about 3.5 to about 5.5. The low C/N ratio of sludge indicates that the organic matter contained in such material is already in a more advanced state of decomposition than that of the forest humus or farmyard manure. Its N, therefore, is more readily available to the plant. The physical properties of forest humus (water retention and percentage of organic matter) far exceed those of sewage sludge. But, while the mineral content in P and K is almost equal in sludge and humus, Ca is much greater in sludge, but Mg content is less. The mean K and P content of farmyard manure is higher than in sludge or forest humus (table 1).

Physico-Chemical Properties

Because the sludge samples were collected during different seasons, the variation in mineral nutrient content was noticeable. In Quebec, Ca is the major variable; this is explainable. During winter, calcium chloride is applied to streets at the rate of 1 ton per mile, and at much higher rates at stoplights, intersections, and hills, varying with the hill slope. Thus, sludge samples collected in winter or spring after snowmelt contain much more Ca than when collected during

summer. Also, according to Lunt (1959), Garner (1966), Scott (1969), and Sopper (1970), the chemical properties of sludge are influenced by industrial and other wastes flowing into main sewers. Hence the material is variable in its chemical content. Similarly, the mineral content of farmyard manure is not constant, varying with the livestock and kind of fodder and bedding.

According to Anderson (1956), the mean composition of digested sewage sludge tends to correspond to the fertilizer grade 2.4-2.3-0.3 (N-P-K). The sludge used in my study correspond to about 2.0-1.1-0.4, and the farmyard manure used earlier at Grand'Mère to 1.4-1.7-2.5. The effectiveness of NPK values for sludge and farmyard manure for tree growth cannot be compared with identical values found in commercial inorganic fertilizers. Sludge and farmyard manure possess the most important growth factor, the capacity to retain water; commercial fertilizer does not possess this.

An interesting difference in P content is shown between sludge from Ohio and from Quebec. Ohio sludge contains from 3,000 to 14,000 p.p.m. of P, and Quebec 1,000 to 2,000 p.p.m. The Ohio material is richer, but more variable. Scott (1969) commented that the use of detergents and kitchen-sink macerators has considerably increased the quantity of P in sewage sludge.

In some ways the value of sludge as a forest fertilizer does not compare with forest humus. By its greater bulk and incorporation with mineral particles, humus imparts more desirable physical properties. In contrast, the effect of sewage sludge on physical soil properties is bound to be better than that of inorganic fertilizer, the effects of which in physical terms are practically nil. Moreover, sludge is also a soil amendment, and, from examination of tables presented by Lunt (1959) and Berrow and Webber (1972), sludge contains important quantities of trace elements necessary for

nutrition to a greater extent than most commercial inorganic fertilizers.

Perhaps the most important asset of sewage sludge over inorganic fertilizers is its ability to retain water and to release nutrient elements slowly and longer. Commercial fertilizers have a quicker effect on tree growth, but this effect can be expected not to last as long as the more slowly decomposing sludge.

My experiment has not as yet, gone far enough to allow the value of digested sludge on tree growth to be compared with farm manure. But according to Lunt (1959), digested sludge compares favorably with farm manure used in agriculture, and its effect lasts longer. Today, as the supply of farm manure is becoming more and more limited, sludge could be a good substitute not only for agriculture but also for forestry.

For agriculture purposes, Le Riche (1968) has indicated that

heavy metals from industrial effluents can accumulate in sewage sludge and constitute a hazard if taken up by crops growing on sludge-treated soil.

However, Le Riche's experimental evidence failed to fully support this contention, as the plants he studied did not take up abnormally large quantities of heavy metals. Le Riche's opinion is nevertheless shared by Berrow and Webber (1972), who wrote that heavy rates of sludge application over a number of years can constitute a hazard. It must be pointed out that the studies carried out by Berrow and Webber (1972) were made on a site on which 10 tons of dry sludge per acre was applied during 7 years.

In forestry there is no apparent problem, and the greatest use for sludge will be on trees growing on sandy sites that are always low in water-holding capacity; on plantations established on abandoned farmlands deficient in organic matter; and in nurseries where microbiological

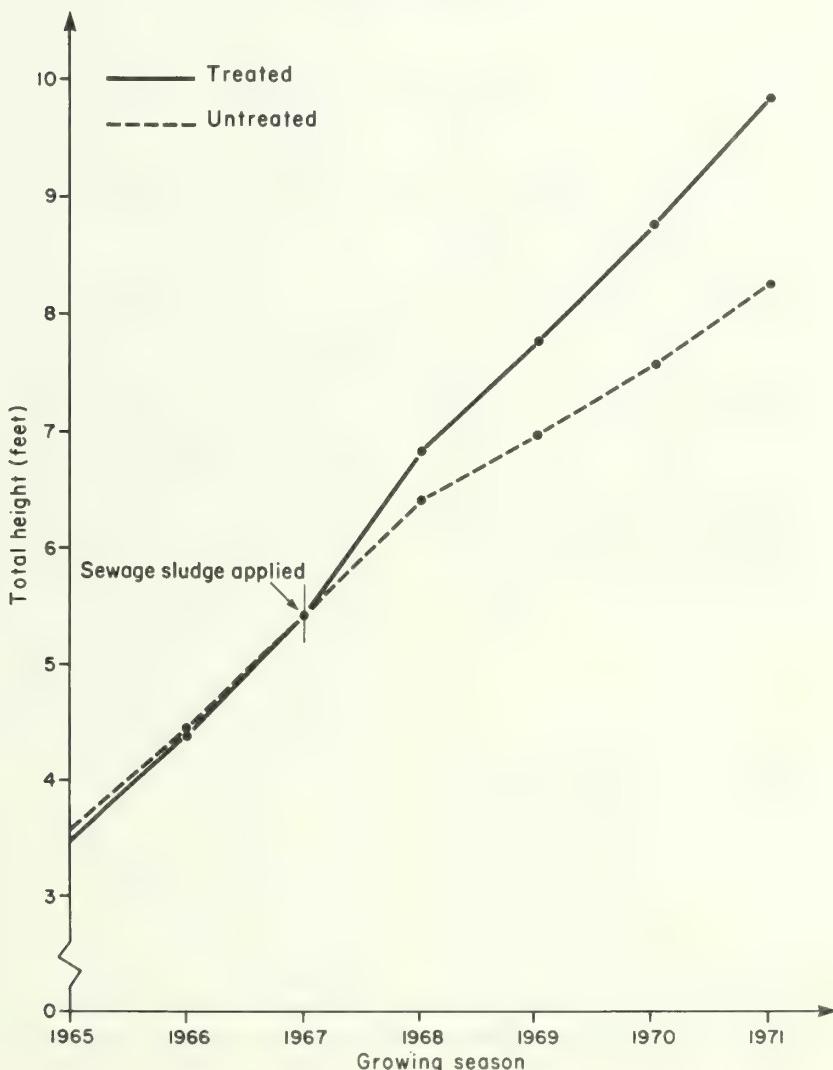
activity is reduced by weed-killer. Sludge is also acceptable for growing Christmas trees and preparing seed orchards.

Height Growth

Before sludge was applied, the total height of the trees to be treated in 1965, 1966, and 1967 was similar to that of control trees. In fact, the height-growth curve in 1965 and 1966 followed a similar pattern for both sets of trees, giving in

1967 an insignificant "t" value of 1.65 and a mean height difference of .03 foot (9 cm.). The "t" value of 1.65 for such a small height difference indicates that tree pairing was precise. During the first year after sludge application, the height of the treated trees exceeded that of the control trees by 7 percent, with a "t" value of 4.29, representing a difference in height significant at the $P=0.001$ level. In subsequent years this difference became

Figure 1.—Average total height of white spruce on treated and untreated sites.



even greater, reaching 30 percent after 4 years. Indeed, from the end of the 1967 growing season to the end of the 1971 growing season, the height of the control trees increased by 49 percent, and the treated trees by 79 percent.

This marked and speedy height-growth response to sludge indicates its value as a growth stimulator. Furthermore, as the mineral nutrient content of sludge is released slowly, due to its organic nature, nutrients are more steadily absorbed by tree roots. Consequently, the beneficial effect of sludge on tree growth can be expected to continue longer than that from solely mineral fertilizers.

An objection to sludge might be its slow decomposition, which could cause environmental pollution. But it has been demonstrated by Thomas and Bendixen (1969) that soil microorganisms utilize most of the organic carbon of sludge and that even wide soil-temperature variations during the season have no effect on the rate of degradation of organic carbon. According to the same authors, the addition of sludge to sandy soil at the rate of 6.8 tons/acre yearly and for several years has not shown an accumulation of organic residue. Hinesly and Sosewitz (1969), in discussing the use of digested sludge, reported that when scattered on soil it did not encourage flies or give off a disagreeable odor. My experiment confirms this.

FUTURE

Water pollution is already critical in Canada. Almost all municipalities discharge waste-water solids, inadequately treated or not treated at all, into water courses. In Quebec province, 400 tons of sewage sludge is discharged daily into watercourses; the equivalent of various solids discharged into rivers by the 54 pulp and paper mills. Although legislation is to be introduced by Quebec to force the pulp and paper mills to reduce

this amount in 1974 to 240 tons a day (1 percent per ton of production), nothing has been done to control the vast quantities of sewage sludge, except extravagant wishes (*pieux voeux*) that cause conflict between government, industries, and municipalities. It is my opinion that the public will keep this conflict alive by demanding action. The time has arrived, therefore, for researchers to listen to and take action on opinion expressed by the public.

I maintain that the most rational solution to water pollution is to return waste to the land, where it belongs. A global solution would be to install in large urban areas a compost mill that would receive town refuse, and all sewage sludge, bark, and sawdust. In Montreal, town refuse is collected at about $\frac{1}{2}$ ton yearly per person, and 85 percent of the refuse (50 percent paper products, 32 percent food waste, 3 percent wood) could be turned into compost. Of the remaining 15 percent, 7 percent metals and 5 percent glass, could be separated at the mill and sold, and 3 percent ash, rocks, dirt, etc., could be used as landfill.

An estimate for the Quebec metropolitan area—population 400,000—showed that an economical return could be expected from a compost mill (DANO type) that would be paid \$5 per ton for refuse collected from the city; and after treatment the loose compost would sell at \$5 per ton, and \$20 per ton for compost packed in 50-pound bags, all prices f.o.b. mill. The mill was to be equipped with a crushing and mixing machine, to receive yearly, in addition to the 160,000 tons of compost derived from town refuse, 10,000 tons of sludge from metropolitan Quebec, 45,000 tons of bark from three pulp and paper mills, and a certain quantity of sawdust waste produced in the Quebec region at a rate of 1 cubic foot per 1,000 board feet. Bark and sawdust wastes are known as soil amendments in agriculture and forestry.

To reuse the 4,000 square miles of

abandoned land in Quebec province, reforestation is necessary. Located between Quebec city and Montreal, 600,000 acres of this land are sandy soil, deficient in nutrients, and similar to the soil of the Grand'Mère experimental area. Elsewhere in the province, 7 million acres are still under cultivation and need yearly soil amendment. There is an obvious market for organic soil amendments in forestry and agriculture, but before the benefit of compost application can be known, the selling price must attract customers.

Putting sewage sludge and urban and industrial waste back on the land where it belongs will occur sooner than we think, because it is the most acceptable and economical method of combating pollution created by other means of waste disposal. But researchers should continue to determine the optimum amount of waste disposal for maximum growth.

CONCLUSION

From this study on the effect of digested sludge on the height growth of a 10-year-old white spruce plantation established on sandy soil, it can be concluded that sewage sludge is a potential forest fertilizer of great value, and its use could turn an environmental pollutant into a financial asset.

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WILDLIFE MANAGEMENT- FOREST FERTILIZATION RELATIONS

by DONALD F. BEHREND, *Senior Research Associate,
State University of New York College of
Environmental Science and Forestry, Newcomb, N. Y.*

ABSTRACT. There is a dearth of information about comprehensive management systems, and little more than crude speculation about forest fertilization-wildlife management relationships. To elucidate these relationships, studies of fertilization—including various combinations of goals and techniques—should be conducted. This research should include studies with timber production as the primary objective, with wildlife primary, and with neither favored.

HERE IS an abundance of information about the effects of fertilization on forest plants, and there is some information about the effects of fertilization on the nutritional quality of wildlife food. Some information is also available about the relative attractiveness of fertilized and unfertilized plants to herbivores. Thus it might be concluded that management systems utilizing this information are currently employed in forest-resource management. However this is not true: little more than crude speculation has actually been accomplished about the relationship of forest fertilization to wildlife management.

This paucity of information about fer-

tilization-wildlife management relationships is not the result of a lack of interest or recognition of the potential importance of the problem. Hilmon and Douglas (1967) recognized the potential importance of forest fertilization to wildlife, stating that fertilization could affect the yield and nutrient content of food plants, their composition in the forest, and the rate of succession. They added that the potential for unfavorable response—damage of fertilized vegetation by wildlife—must also be recognized. This distinction, a favorable or unfavorable response depending on primary management objectives, permeates the bulk of the literature; and, in my opinion, this is

responsible for the dearth of information about a comprehensive approach to forest management, including fertilization.

FERTILIZATION AND WILDLIFE FOODS

Williams (1969) has provided a partial review of the literature about the effects of fertilization on the nutritional quality of wildlife foods. Several investigations (Wood and Lindzey 1967; Bailey 1968; Oh et al. 1970; and Ward and Bowersox 1970) have found that N fertilization resulted in increases in crude protein in deer (*Odocoileus* spp.) browse. Bailey also found that mixed fertilizer, containing N, P, K, Mg, and S affected protein levels in the same manner as N fertilizer alone. However, the mixed fertilizer stimulated growth, thereby producing more browse, probably by lessening the P deficiency in the soil (Bailey 1967).

Wood and Lindzey, Ward and Bowersox and Oh et al. all found that deer preferred fertilized browse over unfertilized browse; and Oh et al. also found that N fertilization increased the fermentability, hence digestability, of Douglas-fir (*Pseudotsuga menziesii*) seedlings.

The results of Wood and Lindzey and Ward and Bowersox led them to state that the carrying capacity of forested areas for deer could be increased through fertilization. Wood and Lindzey went farther, stating that fertilization opens up the possibility of shifting herds locally from one parcel to another. Bailey cited the 13-percent increase in protein he observed as indicating great potential for managing browse quality. But he added that it is not known what this would mean to overwinter survival, reproductive success, or herd productivity.

Other references to fertilization and forest wildlife are concerned mainly with food patches rather than existing vegetation (Mayer-Krapoll, 1956; Webb and Patric 1961; Yoakum and Dasmann 1969). Still other reports are concerned

mainly with the negative aspects of wildlife relative to forest fertilization. Thus Hilmon and Douglass cited problems with snowshoe hares (*Lepus americanus*) browsing fertilized conifers (Heiberg and White 1951) and squirrels preferring cones from fertilized slash pine (*Pinus elliottii*) (Ahser 1963). Mustonoja and Leaf (1965) cited several reports about the serious silvicultural problem due to the attractiveness of fertilized plants to animals.

I believe that the major biological relationships of forest fertilization relative to wildlife are reasonably clear. First, the nutritional quality of plants as food for wildlife can be increased. Second, the quantity of food may be increased. Third, herbivores will eat fertilized plants in preference to unfertilized plants. All this may result in increased survival and reproduction and improvement in the condition of individual animals.

The management implications of this are far less clear, and considerable work will be required to elucidate them. To that end the following approach is outlined.

FERTILIZATION AND MANAGEMENT

Wildlife may or may not be considered a high-priority management objective on a given forest area; but as many species eat plants, it must nonetheless be considered. I believe it is thus essential to initiate studies of forest fertilization where various combinations of management goals and techniques are employed. Studies of wood and wildlife production should be conducted on areas where wood is the primary objective, where wildlife has priority, and where neither is favored.

Further, the spatial and temporal relationships between fertilization of forest stands and of wildlife food patches must be ascertained. This could be approached by intensive plant and animal studies on

areas involving no fertilization, fertilization of food patches only, fertilization of forest stands only, and fertilization of both.

Such studies would permit sound inference on the real, as well as potential, value of fertilization in increasing carrying capacity, and even in increasing populations. The proposed research would also be valuable in determining the real value of fertilization in controlling distribution of herbivores in time and space. The potential for thus concentrating animals in northeastern forests is illustrated by concentrations of large numbers of white-tailed deer (*O. virginianus*) feeding on aquatic vegetation (*Behrend 1966*) that has a relatively high ration of Na to K (*unpublished report by Behrend, Tierson, Leaf, and Halinar*).

Before such studies can be realistically conceived, planned, and executed, it is imperative that foresters and wildlife managers join hands as forest-resource managers. Until then, we are unlikely to know much more than we do today; that is, that forest fertilization has great potential for wildlife, and that wildlife is a great potential problem in forest fertilization.

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URBAN FORESTRY AND RECREATION DEVELOPMENTS IN RELATION TO FERTILIZATION

by NORMAN A. RICHARDS and RAYMOND E. LEONARD,
*respectively Associate Professor, State University of
New York College of Environmental Science and Forestry,
Syracuse, N. Y.; and Research Forester, USDA Forest
Service, Northeastern Forest Experiment Station,
Durham, N. H.*

ABSTRACT. Urban and recreational forest areas present complex problems because of heavy use pressures, but their higher values increase feasibility for intensive management inputs such as fertilization wherever benefits can be shown. Situations in which fertilization is potentially useful are explored, including sites recently developed on stripped soils or poor quality made land, rehabilitation of sites deteriorated by overuse, treatment of vegetation damaged by direct or indirect people pressure, and treatments to counteract eutrophication effects on heavy use sites. Potential adverse effects of mass fertilization in urban and recreational forests are cautioned against. Fertilization needs to be developed as a more sophisticated tool to aid establishment, rehabilitation, and management of desired vegetation.

LAND MANAGERS in the Northeast are becoming increasingly involved with the management of vegetation under heavy urban and recreation pressures. The forestry profession has much background expertise that can be used in managing people-stressed vegetation. But compared to traditional forest management, this concern with heavy people pressures does present some new dimensions in focus, problems, and their potential solutions.

FEATURES OF URBAN AND RECREATIONAL FORESTS

We define urban and recreational forest as any area on which trees or under-story vegetation are maintained primarily for their direct influences on people. These are areas subjected to heavy human pressure. Many of them are profoundly disturbed, both in developing the values sought and in the continuing process of their use. On ever more acres of

northeastern woodland, human hooves are replacing cows' hooves as a significant force degrading soils and vegetation. Added to this are related effects of heavy use—construction, drainage changes, chemical additions, etc.; so many complex problems can be expected.

On the other hand, relatively high values are at stake in these vegetated areas. If a treatment such as fertilization is biologically effective, it is very likely to be economically feasible. We believe this opens up a much broader range of management potential than has generally existed for more traditional forest management in the Northeast.

Another feature of these areas is that we are generally concerned with a broad range of vegetative types and conditions. Though trees commonly provide the dominant vegetative structure, many of these areas are not fully forested landscapes. Other vegetation may be important: grass, especially in high impact areas; forbs and other ground-cover plants on less trampled areas; and shrubs located to serve as barriers, for wildlife food and cover, or for aesthetic effects.

In some special cases, protection of a unique biotic community is of prime concern. But more commonly, our concern is for a general vegetation effect to be maintained as long as possible with minimum inputs. Much substitution among species is possible. For example, pitch pine may serve as well as or better than white pine, beech as well as sugar maple. Criteria for suitability are often more flexible than for timber: the vegetation must only survive, grow, and produce the general effects desired.

SITUATIONS IN WHICH FERTILIZATION IS POTENTIALLY USEFUL

1. *Sites recently developed on areas stripped of surface soil, or on man-made land covered with poor soil material.*

Here the need is to accelerate development of soil productive enough to support satisfactory plant growth. Assuming that physical conditions, drainage, etc. are satisfactory (though frequently they are not), then low organic matter levels are a common problem. Direct additions of organic matter are generally feasible only for very intensive development, or where large quantities of organic waste are readily available, can be economically spread, and have no objectionable effects. For many relatively extensive forest recreation sites, it may be more practical to take the much slower tack of growing the organic matter in place, stimulated by inorganic fertilization.

Good examples of this are mountain ski slopes where the A and even B horizons have been scraped away during slope construction. At Whiteface Ski Center in the Adirondacks, fertilization and liming of such sparsely vegetated upper slopes increased grass and forb dry matter above-ground from 270 g./m.² on control plots to 500 g./m.² on the treated plots only 3 months after treatment. There were probably similar increases below ground. Though it would take several years to build up soil organic matter in this manner, the immediate benefits of improved soil cover for reduced erosion and better snow base were accomplished.

A more extreme example is an industrial waste area near Syracuse, N. Y., which is now public land and a potential future park site. Here the fine lime waste material is very unstable and unsuitable even to walk on in its sparsely vegetated condition. But addition of P and N, the known deficient elements in this case, increases above-ground dry weight of grass and forbs four- to six-fold, greatly reduces erosion, and provides enough cover to support light pedestrian traffic.

In both examples, the fertilizer costs are very modest for the effects obtained. The big problem is in getting management to recognize the results as desirable enough to take action. On the ski slope, fertilizer is most needed on the upper slopes that are hardest to fertilize, so most present fertilization is on the lower slopes which already are heavily vegetated. On the industrial waste site, no agency is yet taking responsibility for site improvement. Without changes in management approaches, such research results remain academic.

2. Rehabilitation of sites deteriorated by overuse.

Implicit in the terms *rehabilitation*, *deterioration*, and *overuse* are a complex of value judgments involving some concept of site carrying capacity for people. Carrying capacity involves the resolution of two sets of variables: the physical/biological situation and the cultural demands. Considering a model of carrying capacity as a function of management inputs, we can imagine several possible forms of response curves. For example:

- A modest input to overcome a critically limiting factor may result in a substantial gain in carrying capacity, but increasing the same kind of inputs may have little additional benefit. Single site-rehabilitation techniques, or fertilizing with a critically limiting nutrient, would be examples of this.

- Or we may produce a stepwise pattern of increases by inputs to correct each limitation as it becomes obvious.
- Or an integration of management inputs—controlling structures with fertilization, special plantings, etc.—may produce fairly steady increases in carrying capacity with increasing management intensity.

Thus, for management inputs such as fertilization, we need to know not only what treatments do how much for site rehabilitation under what conditions, but more specifically, we need to know the nature of the response curves. It is actually more complex than this because the cultural element of carrying capacity itself involves a balance between two sets of variables: the number and kinds of people to be served, and the qualitative values these people expect of the landscape. So the result is a three-dimensional response surface upon which management decisions must be made.

We are very short of good information for doing this. But one attempt at such information is in progress in the White Mountains of New Hampshire in a cooperative effort by the Forest Service, the Appalachian Mountain Club, and the College of Forestry at Syracuse. Initial efforts are currently in a graduate-student project primarily to sort out the role of direct vegetation management, including fertilization, versus people control in Tuckerman's Ravine. We hope to expand this in the next few years to other sites and management variables.

A question one often encounters in site rehabilitation is engineering versus biotic approaches. Though biological solutions are generally preferred where feasible, it is often necessary to stabilize a site *for* vegetation rather than *with* vegetation, especially where very active erosion is in progress. Biotic approaches most commonly involve grasses and other effective groundcovers, either existent or planted; and intensive fertilization is a usual and

often essential treatment for their establishment and maintenance.

A good example is work by a Syracuse College of Forestry-Forest Service Team—Ketchledge, Leonard, and others—to stabilize erosion and preserve fragile native vegetation on heavily trampled alpine areas on Adirondack high peaks (*Ketchledge and Leonard 1970*). The native dwarf shrubs, sedges, and clump-grasses are poorly adapted to resist trampling. However, the stoloniferous grasses, red fescue (*Festuca rubra L.*) and Kentucky bluegrass (*Poa pratensis L.*), native in the region on better soils, are highly resistant to trampling. But they can be established on the acid, organic alpine areas only with intensive fertilization (N,P,K,Ca, and Mg).

On eroded areas where fine soil material remains, grass establishment is excellent even on heavily trampled trails. Where the fines have washed and blown out, leaving only a coarse peat mat, grass establishment is very poor; and engineering structures such as log barriers, stone riprap, etc. become very useful for holding fine soil in place. The grass areas should protect the remaining native vegetation community from further destruction by erosion, and we are hoping, with some promise to date, that native plants may reinvade areas stabilized by grass. However, some control of use will probably be needed to permit substantial recovery here, as has also been the experience in some U.S. National Parks (*Lindsay 1971*). We feel that urban and recreation forest managers must become more involved in all the variables of carrying capacity.

3. Treatment of vegetation damaged by direct and indirect people pressure.

Much cost and pain of site rehabilitation can be avoided if we can treat vegetation in its early stages of damage from people pressure. It is widely accepted that maintenance of high fertility may

serve to compensate for a number of ills befalling vegetation under heavy use pressure. A vigorous plant community, with heavier foliage and thicker stems and bark, may be more *resistant* to damage—provided that it is genuinely healthy growth and not just highly succulent growth such as may result from heavy N fertilization. Vigorous plants are also more *resilient*; they recover more rapidly from damage. That an ounce of prevention suggests bushels of cures is evidenced by the frequency with which amateurs and professionals use fertilizer as a shotgun treatment for ailing plants, occasionally with some success. Perhaps a broader approach is in order.

To stop site degradation before it becomes serious, it is useful to view site degradation as the net result of *degrading* and *rehabilitating* processes. For example, damaged or removed plant parts are regenerated, lost litter and soil organic matter are replenished, compacted soil is loosened by frost action and biotic activity. The critical point occurs when the recovery processes begin falling substantially behind the degrading processes. There are no doubt many situations in which fertilization is helpful in holding this balance, but it is probably naive to count on it universally.

A sounder approach is to reduce the cause of damage as much as possible. One important factor is the seasonality of use pressures and their effects. Heavy use concentrated in a few summer months leaves several open months for recovery, whereas heavy spring-to-fall use does not. We are beginning to suspect that light use in spring, in the month after snow melt when soil is saturated and vegetative cover is at its annual minimum, may be far more detrimental than heavier use in mid-summer to early fall when soils are drier and vegetation is at its maximum. It is possible that careful seasonal timing of fertilizers to favor early spring growth of grass spe-

cies might partially counteract these effects on some sites.

Site damage is of course lightest under good snow cover, and vigorous low vegetation is effective in maintaining snow. We do know that snow compaction may have adverse effects on plant microclimate and aeration, but to our knowledge plant vigor/snow compaction damage relationships have not been explored much on recreational lands. Perhaps the turfgrass specialists can give us some clues on this.

Pollution damage to plants is an increasingly important indirect effect of heavy people pressure. One might expect vigorous well-fertilized vegetation to either resist better or recover from periodic high air-pollution levels, and this is documented in at least one case: apparent ozone damage to Kentucky bluegrass in Maryland was greater on plots with moderate than with heavy N fertilization (146 vs. 293 Kg. N/ha.) (*Wilton et al. 1972*). Though differences in apparent pollution damage to trees among sites and individuals have been observed (*Wood 1968*), we are not aware of any studies of the role of fertilizer in reducing pollution damage to trees.

4. Treatments to counteract effects of land eutrophication on heavy-use sites.

Though we have often been aware of nutrient losses from intensively used sites due to erosion and plant or litter removal, the reverse process—land eutrophication—is more subtle. On urban and recreational forest sites where vegetative cover is maintained, erosion is reasonably controlled, and soil leaching is reduced by compaction, site eutrophication can be expected in time. A good example of this is Tuckerman's Ravine in the White Mountains, where many decades of nutrient concentration due to intensive camping activity has resulted locally in abnormally high fertility status for a mountain site.

To the extent that this builds up a balanced nutrient status, it may simply reduce needs for additional fertilizer inputs. However, unintentional mineral inputs may often lead to imbalances in certain nutrients or excesses of potentially toxic materials. This suggests that routine fertilization will need increasingly to be replaced by more specific formulations to correct imbalances. Calcium salts on roads (summer and winter), concrete, and wood ashes are a few of many sources of increased base status locally. While these may be beneficial in extremely acid soils, under more neutral conditions they may create nutritional problems for acid-soil plants—ericaceous plants, certain oaks, etc. Iron deficiency due to Fe immobilization is an increasingly observed problem for these plants in urban, recreational, and roadside areas, requiring repeated use of chelated iron fertilizer even where total native soil iron is high.

Damage to trees by road salting, especially where these salts accumulate in roadside drainage, has received much study in New England (*Holmes 1961; Rich 1968*). Treatment with gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) has been recommended for these accumulation areas, but the long-term solutions lie in more careful and restricted road salting and better road-drainage design. For the sake of the total roadside community, we hope that changes to more salt-tolerant species will generally be considered only as a last resort. The obviously susceptible species are valuable phytometers here.

Accumulations of excess heavy metals are gaining more recognition as local problems. For example, wildlife specialists are increasingly concerned about lead accumulations along highways. Though liming has been shown to depress availability and uptake of heavy metals such as lead (*Cox and Rains 1972*) and suggests a stop-gap solution, we hope that the current campaigns to curtail heavy-metal inputs to our land-

scape will succeed in reducing this problem in the long run.

PUTTING FERTILIZATION IN BALANCE IN URBAN AND RECREATIONAL FORESTS

So far we have sought to show that fertilization is a potentially feasible treatment for many vegetation-soil problems in urban and recreational forestry, probably more so than in wildland forestry in the Northeast. Now we feel obliged to sound the cautions.

Because of the high use-values involved, the relative cheapness of fertilizer, and the widespread popular belief in its magical qualities, fertilization is rapidly increasing in the urbanizing Northeast and hardly needs more selling as a mass treatment. It is obvious that urban-suburban fertilization is rapidly surpassing agricultural fertilization in the Northeast as an important potential source of water pollution.

More subtle are the potential effects of indiscriminate fertilization on existent wild to semi-wild plant communities and their management. Many plant communities in our landscape depend on the relatively low fertility of their sites for protection from more aggressive invaders. This includes heaths, old-field poverty grass-mixed forb communities, fern glades, etc., which may often provide very satisfactory cover requiring little maintenance. Fertilization can destroy

these communities, in some cases replacing them with more aggressive noxious weeds, and often increasing the need for mowing, brush cutting, and other control measures.

Thus there seems little justification for fertilization as a routine mass treatment in urban and recreational forests. Rather, it must be further developed as a highly sophisticated tool for aiding establishment, rehabilitation, and maintenance of desired plant communities.

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INSECT AND DISEASE CONTROL: FOREST FERTILIZATION RELATIONS

by ALEX L. SHIGO, *Chief Plant Pathologist, USDA Forest Service, Northeastern Forest Experiment Station, Durham, N. H.*

ABSTRACT. Insect and disease control in the past emphasized reduction of damage to trees grown for wood products. Now control measures must include reduction of damage to trees in scenic areas, recreation sites, watersheds, and rural areas. Fertilizers are being considered for control, in combination with other materials. Some effects of fertilizers on insects and diseases are discussed.

INSECTS AND DISEASES cause considerable damage to trees not only because of their adverse effects on timber quality and quantity, but also because of their effects on trees in recreation areas, watersheds, scenic areas, backyards, and cities. All insect and disease problems must now be approached from this broad view, rather than strictly from the timber aspect. This means that we must change our views about what is and what is not a financially feasible control for a damaging insect or disease.

The use of fertilizers on trees has been aimed primarily at increasing growth, or to satisfy the timber requirement. In the last decade, many reports, mostly from Europe (*Foster 1967*), have pointed out that fertilizers also affect insects and diseases. The effects range from greatly increasing the injury caused by insects and diseases to greatly decreasing the injury. Reports in the literature conflict greatly.

Insects and fungi have received most attention from tree entomologists and pathologists. Although this trend will probably change little in the future, other destructive agents or stress factors have been receiving more attention in the last decade; and they will probably continue to receive more attention in the future—viruses, mycoplasmas, bacteria, nematodes, pollutants, environmental extremes, and man and his activities.

Insects and fungi often interact with these other stress factors. It could be that the results reported by some investigators conflicted because they focused on one destructive agent whereas actually interactions of several agents were involved.

The addition of fertilizers to the soil and tree triggers a multitude of events. It would be extremely unwise to treat lightly the subject of fertilizers as they affect insects and diseases. This is one

area where tree entomologists and pathologists must interact. A fertilizer treatment may indeed increase growth and reduce the injury caused by a certain insect, but it may also increase the susceptibility of the tree to an aggressive pathogen.

The use of fertilizers on ornamental woody plants and annual crop plants has been practiced for many years. A vast amount is known about the effects of fertilizers on these plants. It would be profitable to learn as much as possible about the effects of fertilizers on ornamental and annual plants. Much of the basic information is applicable to trees.

Foster (1967), in a comprehensive review, discussed the effects of fertilizers on some of the economically important insect and disease problems. He gave information about insect and disease situations that are increased and decreased by fertilizers. I will not repeat this information, but will supplement it with some brief additional material to show the complexity of the subject; and I will mention some stress factors other than insects and fungi.

PHENOLS AND RESISTANCE

A great amount of information is known about healthy trees (Kozlowski 1971) and diseased trees (Smith 1970). Much of what is known about the biochemistry and physiology of diseased plants (Goodman *et al.* 1967 and Tomiyama 1963) is applicable to trees.

Phenol compounds play a major role in resistance of plants to disease. After wounding, oxidation of phenols occurs; and these oxidized products act as deterrents to infection. Nitrogen fertilizers often increase susceptibility of plants to infection by rust fungi while at the same time the amount of phenols is decreased. In trees, the same situation was found with the leaf-infesting fungus *Venturia inaequalis*. Kirkham (1954) showed that the ratio of soluble nitrogen to phenol

compounds affected resistance of apple and pear leaves to *V. inaequalis*. Szwejkowska (1959) gave a possible explanation for this by stating that aromatic biosynthesis and nitrogen metabolism may be regarded as competing pathways.

NUTRITIONAL PLANT CHANGES THAT AFFECT INSECTS

Rodriguez (1960) pointed out that fertilizers and other agricultural chemicals can change the composition of plants quantitatively, and consequently, their nutritive value for insects. An excellent discussion on the role of nutritional principals in biological control was given by House (1966). He stressed two important basic laws about food for insects: the food must possess characteristic properties that attract and induce an insect to feed; and the food must contain substances that fulfill the nutritional requirements of the insect. Anything, such as fertilizers, that alters these two basic characteristics of a foodstuff will alter the feeding pattern of insects. Further, an altered food base will also alter the feeding patterns of insects that feed on other insects, leading to an alteration of natural biological control patterns.

MYCORRHIZAE

The role of mycorrhizae in plant nutrition is well known. Marx (1971), working on a hypothesis of Zak's (1964), showed that ectomycorrhizae plays a protective role in reducing infection of feeder roots of pine by *Phytophthora cinnamomi*. Harley (1963) stated that the ectomycorrhizal habit is an adaption in some species to nutrient-deficient soil. Ectomycorrhizae are more prevalent in infertile soils (Voigt 1971). Recent results on the effects of fertilizers on mycorrhizae from Europe indicate that, depending on the fertilizer combination used, mycorrhizae usually increase (Koberg 1966; Göbl and Platzer 1968).

Many exceptions can be found. Richards and Wilson (1963) showed that by increasing soil N by adding NH_4NO_3 and lime, mycorrhizal development was reduced. If ectomycorrhizae are acting as protective barriers to other root-infecting fungi, then great care must be given to the amount and combination of fertilizer used, or the results could be more harmful than beneficial.

NEMATODES

Nematodes are common in forest soils (Shigo and Yelenosky 1960). Many forms feed on tree roots and cause injury. Some nematodes are vectors for viruses (Hewitt *et al.* 1958) while others feed on mycorrhizal fungi (Kuehle and Marx 1971). Dwinell (1967) showed that combinations of N, P, and K that altered susceptibility of *Acer saccharum* and *Ulmus americana* to *Verticillium dahliae* also altered the adequacy of the hosts to the plant parasitic nematode *Pratylenchus penetrans*.

VIRUSES

Different cultural practices affect plant susceptibility to viruses. The better plants are fed and grow, the more likely they are to become infected (Broadbent 1964). The principal vectors for viruses are sucking insects, and these are the insects that increase in numbers when fertilizers are used (Rodriguez 1960; Watson 1964). Many examples of increased susceptibility to viruses following increased nitrogen fertilization for crop plants are given by Broadbent. He stated that the increased amount of nitrogen affected susceptibility more than it affected the population of insect vectors.

INSECTS AND DROUGHT

Population density of many needle-eating insects of spruces and pines may vary greatly at the same time at different locations, or at the same location at different times (Schwenke 1966). Schwenke (1966) correlated these differences with differences in the moisture content of the soil. Further, he showed that, the lower the mortality rate of the larvae, the higher the weight of the pupae; and the shorter development time always corresponded to higher concentration values of the cell sap.

Results corresponding to this were obtained with fertilizers. Trees that had been treated with fertilizers, principally nitrogen, reacted to the harmful insects like trees on more humid soils; that is, through application of fertilizers, the propagation of the insects was checked. The sugar content of the needles was reduced on soils having a higher moisture content, during more humid weather, or on soils to which fertilizers had been applied. The nutritive value of the needles was decreased, and the propagation of the respective insect species was checked.

POLLUTANTS

The list of pollutants and combinations of pollutants that injure trees is increasing steadily. Cotrufo and Berry (1970) pointed out that fertilization with NPK improved the tolerance of white pine (*Pinus strobus*) to SO_2 injury.

UPTAKE OF ELEMENTS FROM SOIL TO WOOD IN LIVING TREES

Ellis (1959) showed that the quantity and quality of the minerals in the soils supporting grand fir (*Abies grandis*) was reflected in the wood. There were significant differences in mean values of most elements in buttwood ash of trees grown west and east of the Cascades. Wood de-

cayed by the fungus *Echinodontium tinctorium* showed an increased ash content and an apparent accumulation of certain elements. Decay by *E. tinctorium* was found only on the east of the Cascades. Cowling (1970) pointed out that nitrogen is just as essential for the growth of wood-destroying microorganisms as it is for other organisms. Fertilizers may increase growth of the trees, but they may also increase growth of wood-destroying microorganisms.

CONCLUSIONS

The benefits of fertilization have been demonstrated overwhelmingly with food crops. Often to attain the desired benefits with food crops, resistant varieties are used in combination with intensive fertilizer and pesticide programs. But the problems are manyfold greater with trees. A greater quantity of food is the only goal with annual food crops. With trees, there are many goals, depending on where the tree is—forest, recreation area, watershed, city, or backyard.

We want and need trees for many reasons. We must assess the value of fertilizers in a new light. Fertilizers can do more than just increase growth. Used properly, fertilizers can increase the resistance of trees to certain insects and diseases. In many situations, healthy trees relatively free of insects and diseases may be the most desirable trees. And, as the values we put on trees change, controls that were considered not economically feasible in the past may be feasible in the future.

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SPECIAL FOREST CROPS AND FOREST FERTILIZATION

by H. W. YAWNEY and R. S. WALTERS, *Project Leader and Research Forester, USDA Forest Service, Northeastern Forest Experiment Station, Burlington, Vt.*

ABSTRACT. The general objectives of fertilization for special forest crops such as maple syrup and Christmas trees are much the same as for other forest products—to increase production and improve quality. The problem of fertilization for increased syrup production is considered under the same nutrient and soil considerations necessary for increased production of other forest crops. Short rotation plus the high potential value of the crop make Christmas trees especially well suited to intensive cultural techniques such as fertilization. The greatest increase in returns to investment occurs when fertilization results in a shorter rotation and increased tree quality.

MAPLE SYRUP and Christmas trees are special crops, but the objectives of fertilization are the same as those for any other forest product—to increase production and quality. The types of responses that are sought are different. In sugarbushes, fertilizer treatments are intended to increase sap-flow volume and sap-sugar content. In Christmas tree plantations, the desired results are controlled growth rate and full crown development with good needle retention and color. Because these products are so different, each is dealt with separately.

SYRUP PRODUCTION

The production of maple syrup from sugar Maple (*Acer saccharum* Marsh.) is limited almost entirely to North America, principally in the northern tier of states from Maine to Minnesota and adjacent Canada. The processing of sap to make syrup is one of the oldest of our agricultural industries, which reached its peak in the United States around 1860 (*U.S. Tariff Commission 1930*) with the production of about 6.6 million gallons. Since then the industry had experienced

a general decline, which has leveled off in recent years at an annual production of about 1.5 million gallons.

It has been estimated that less than 3 percent of the sugar maple trees over 10 inches d.b.h. are being tapped (*Willits 1965*). The potential for commercial maple sap production would seem to be extremely large. But, because of the high cost of labor along with other economic pressures, it is not likely that any large gains in production will be brought about by increasing the number of trees used (*Bell 1955; Foulds and Reed 1962; USDA 1962; Taylor et al. 1967*). Increases are being sought now in existing sugarbushes through improvements in sap-collection techniques and through advances in sugarbush management practices, including fertilization.

The processing of sugar maple sap to make syrup simply involves boiling until the sap has been evaporated to a sugar concentration of 65.5 percent. During the sugaring season, the average sugar content of sugar maple sap is about 2.5 percent (*Gabriel 1964*). According to Jones' (1967) "maple rule of 86", the number of gallons of sap required to produce 1 gallon of syrup is calculated as:

$$\text{Gals. sap} = \frac{86}{\% \text{ sugar}}$$

Thus 34.4 gallons of 2.5-percent sap are required to make 1 gallon of syrup. As sugar content increases, less sap is required. Hence, 28.7 gallons of 3-percent sap, and 24.6 gallons of 3.5-percent sap will yield 1 gallon of syrup.

The economic implications of increasing sap-sugar content are obvious. More syrup could be produced for the same labor and equipment cost, and there would be considerable savings in fuel used for boiling.

Considerable variation in sap-sugar content exists between sugarbushes and between trees in the same sugarbush (*Taylor 1956*). Although sugar content

varies from year to year and during the sap-flow season because of differences in weather conditions, sweeter sugarbushes tend to remain sweeter than neighboring bushes and individual trees are consistent in their performance relative to other surrounding trees (*Jones et al. 1903; McIntyre 1932; Morrow 1952; Taylor 1956*).

There is strong evidence that sweetness in individual trees is an inherited trait (*Kriebel and Gabriel 1969; Gabriel 1972*). Further evidence (*Marvin et al. 1957*) shows that sugar concentration is positively correlated with sap-volume yields. Thus, genetics must be considered as a significant factor contributing to the observed variation between trees, and perhaps to some extent between sugarbushes.

It must also be assumed that a certain amount of this variation, particularly between sugarbushes, is due to differences in environmental factors—specifically differences in site productivity. If this assumption is correct, improvements in site productivity brought about by fertilization would be expected to enhance sap-sugar production.

Increased syrup yields resulting from fertilization have been reported. Kriebel (1961) conducted an experiment in which 600 pounds per acre of N as ammonium nitrate was applied in 12-inch-deep holes at intervals of about 2-1/3 feet around the trees. A significant increase in sap-sugar concentration occurred the first year. This increase averaged about 0.25 percent and was maintained at about the same level over the 3-year period of measurement. Using 2.5 percent as the pretreatment average, the rise in sugar content represented a 10-percent increase. In practical terms, this increase in sugar content would yield 0.3 additional gallons of syrup for each 100 gallons of sap. In an adjacent test stand, no responses were obtained until the third year after treatment.

LaValley (1969) made five annual broadcast applications of N, P, and K amounting to about 18, 6, and 11 pounds per acre per year respectively. A response was noted the second year, when sugar concentration increased 18 percent over the control plot. During the fifth year, sap-sugar concentrations of the fertilized trees averaged 12.1 percent higher than the unfertilized trees. The fifth-year measurements also showed a 10-percent increase in sap volume. Interim data between the second and fifth years were not presented by the author.

Watterston *et al.* (1963) applied N, P, and K separately and in combination to sugar maple trees in central New York. The combined elements were broadcast at the rate of 300, 260, and 250 pounds of N, P, and K respectively—the equivalent of 6,000 pounds of 5-10-5 per acre. When applied separately, 200, 145, and 200 pounds of N, P, and K respectively were used per acre. The various treatments were found to affect total sugar yields either through sap volume or sap-sugar concentrations—and not always in a positive direction. The complete fertilizer application during the first sugaring season after treatment resulted in a significant increase in sap-sugar concentration. But it also resulted in a pronounced decrease in sap volume, with a net effect that total sugar yields were less than those of the controls. During the second season, both sugar concentration and sap volume were greater than those from the control trees, but this increase was not sufficient to compensate for the decrease the first season. The N and K fertilizers resulted in little change from the control trees, while the P fertilizer resulted in a significant decrease in sugar concentration.

In an experiment near Burlington, Vermont, Smith and Walters studied the effects of fertilization on sap production. N, P, and K, broadcast at rates of up to 160, 70, and 66 pounds per acre respectively, with and without 10 tons per acre

of hydrated lime, failed to increase either sap-volume or sap-sugar during four consecutive seasons after fertilization. (Unpublished office report, Northeastern Forest Experiment Station, Burlington, Vt., 1972.)

The few studies reviewed here are all that could be uncovered by the authors that deal specifically with fertilization of sugar maple for sap-volume and sap-sugar production. Obviously much work needs to be done before the effects of fertilization can be evaluated realistically.

Many authors have reported that the ideal sugar tree is a vigorous, fast-growing, well-formed tree supporting a wide, deep crown. Sugar maples possessing these characteristics tend to produce sweeter and greater quantities of sap than slower growing smaller-crowned trees. The implication is that larger crowns have greater leaf surface area and therefore have a greater capacity for carrying on photosynthesis and accumulating reserve carbohydrate. However, Blum (1971) found no relationship between several tree characteristics and sap-sugar concentration.

If form and development are indeed precursors to higher sugar yields, the problem of fertilization for increased syrup production must be viewed in terms of the same nutrient and soil considerations necessary for increased production of other forest crops. It also follows that, for fertilization to be successful, a sugarbush—like any timber stand—must be given proper spacing and be young enough to show a growth response.

A major obstacle to resolving what kind, in what amounts, when, and where to apply fertilizers, is the extreme variation encountered in sap-sugar content and sap-volume flows. For example, Watterston *et al.* (1963) reported that the total sugar yields from their control trees varied by 137 percent from one year to the next. The within-season variation among the control trees was as high as

580 percent. They reported similar variation among the treated trees.

Data from our own sap-production studies in Vermont, have shown similar ranges in variation. This inter- and intra-seasonal variation is due mainly to climatic, genetic, stand, and soil-site factors. Yields can also be influenced significantly by other effects such as depth, location, and number of tapholes, microbial buildup within the taphole, and methods of sap extraction. The latter group are physical factors, and variation from these sources can be minimized in research studies by standardizing experimental technique.

The genetic and environmental factors are not necessarily insurmountable. Our data support the findings of other researchers that individual trees generally are consistent in their performance relative to other trees in the immediate area. One procedure that can be used to cope with the problem of variation is to calibrate individual trees or groups of trees for a certain period of years before treatment to establish a base for comparison. This should be an essential element in the design of fertilization studies as well as in other studies dealing with sugar yields from sugar maple.

CHRISTMAS TREES

The Christmas tree industry in the United States has developed rapidly into a multimillion dollar business, with a strong trend toward producing high-quality trees from intensively managed plantations. A nationwide survey in 1964 showed that 41 million trees with a retail value of \$142 million were marketed (*Sowder 1965*). By 1975, due to our expanding population, it is expected to increase to an annual sale of 48 million trees with a value of \$168 million. There is adequate economic justification for consideration of intensive Christmas tree culture.

The short-term rotation of Christmas

trees presents an excellent opportunity for the profitable use of fertilizers. The time between the investment in treatment and the realization of returns is short. This holds interest charges to a minimum. In addition, the returns from a Christmas tree plantation are potentially high enough to justify intensive culture measures such as fertilization.

However, there are many unknowns in using fertilizers for Christmas tree culture. For instance, growers are unsure which species may need fertilizing, when and which fertilizer should be used, and what quantity of fertilizer is needed (*Richards and Leaf 1971*). Therefore the use of fertilizers in Christmas tree culture remains limited.

Three direct benefits can be derived from fertilizing Christmas trees: (1) reduce so-called "planting shock"; (2) maintain tree growth at optimum rate during the rotation (generally 12 inches per year); and (3) improve tree quality. The first two have the effect of shortening the rotation. Shortening the rotation by even 1 year is a real economic advantage to the Christmas tree grower. Reducing planting shock may increase seedling survival.

Growers are primarily concerned with the third benefit—improved quality. Most Christmas tree producers who use fertilizers said that darker foliage (improved color) was their main reason for fertilizing. Generally, fertilizer response can be seen in needle color, crown density, retention of second- and third-year needles, and increased growth. In addition, there are a number of other elusive characteristics that are directly related to a healthy, vigorous tree—such as reducing the incidence of insect and disease damage (*Larsen 1967*).

On the basis of information gathered from a survey of Christmas tree producers who use fertilizer, Larsen (1967) attempted to determine financial returns from fertilization of white spruce (*Picea glauca* (Moench) Voss), balsam fir

(*Abies balsamea* (L.) Mill.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and eastern white pine (*Pinus strobus* L.). He found that an increase in tree quality brought about by fertilization resulted in a price increase of 25 cents per tree, which increased returns to investment by 2 to 4 percent.

However, a greater impact occurred when fertilization resulted in a shortened rotation. Returns may be increased 10 percent or more if rotations are shortened one or more years. Ideally, a fertilization program would not only shorten the rotation, but would also increase tree quality. Larsen found that when fertilization of white pine resulted in increased tree quality and shorter rotations, the return to investment could be increased by as much as 24 percent.

Maki (1958) warned that an intensive fertilization program is not a magic cure-all, but rather another tool available to help in plantation management. Depending on site condition, improper or unneeded fertilization may cause more problems than it solves. Too-fast growth leads to spindly trees. Weed responses may intensify an already difficult weed-control problem. For example, Thor (1965) found that N fertilizers had a detrimental effect on survival of Fraser fir and white pine seedlings (table 1). The fertilizer was added to the planting hole at time of planting. Thirty grams per seedling were used except for ammonium nitrate, which was applied at 15

grams per seedling. The weeds were intensified to a point of causing a moisture shortage for the seedlings.

Also, fertilization is not retroactive. No amount of fertilizer can remedy previous neglect. It will not change the length of shoots nor the form of the older needles. Fertilizer applied in the final phase of production should be considered as a finishing touch in a program of intensive management.

The species most likely to benefit from fertilization are those that require good sites. For Christmas trees these are Douglas-fir, true firs, spruces, and eastern white pine (Bell and White 1966). Douglas-fir, spruces, and true firs generally grow slowly during the 2 or 3 years after planting. White (1966) indicated that the years of stagnation result to some degree from a combination of limited fertility, water availability, and weed competition.

In Ohio, Hacskeylo (1964) reported reducing the time required for producing salable spruce and fir Christmas trees from 10 to 14 years to 6 or 7 years through fertilization. He reported that "The spruce grew as well as did the pines, but the firs were somewhat slower." The economic advantage—reducing a crop rotation so that almost two rotations can be grown in the same length of time it formerly took for one—is tremendous.

The recommendation not to fertilize Scotch pine (*Pinus sylvestris* L.) is almost universal. The species is an excellent forager and will grow satisfactorily except on sites of exceptionally low fertility. Nor is it recommended to fertilize Scotch pine to correct yellowing in late fall. This change in color is an inherited characteristic related to the seed source and is a response to temperature changes and light quality (White 1966).

The harvest of any crop removes some of the available soil nutrients and may limit those available for following crops.

Table 1.—Survival of fertilized Fraser fir and eastern white pine after two growing seasons

Treatment	Fraser fir	White pine
	Percent	Percent
1. 8-40-0	81	83
2. 7-35-0	77	83
3. 0-63-0	89	86
4. 35.5-0-0	20	76
5. 5-10-5	75	78
6. Check	89	91

Source: Thor (1965).

Successive Christmas tree rotations may reduce site productivity. Wilde (1961) noted that 95 percent of the nutrients in a tree are found in the foliage and young branches. These parts are removed by a Christmas tree harvest. By contrast, nutrient losses are small on most logging operations because the slash (foliage and young branches) is left on the site. Therefore nutrient loss due to successive Christmas tree harvesting may be considerable, and fertilization is necessary to maintain soil fertility.

Both soil tests and tissue tests can be used diagnostically to detect the need for fertilization, but neither have yet been calibrated and perfected for use with Christmas trees. Therefore visual symptoms are normally used to determine Christmas tree fertilizer needs. Poor color—particularly during the growing season—short needles and short growth, early needle drop, and decrease in the number of years the needles persist are general symptoms of low tree vigor. Site conditions such as sparse natural weed cover, presence of mosses, and patches of bare soil are also indicators of low nutrient availability (White 1966).

The nutrient most likely to improve growth and color of Christmas trees in the Northeast is N, except on the K-deficient outwash soils of northern New York, New England, and southern Canada. Urea and ammonium nitrate are excellent and inexpensive sources of N, while muriate of potash is a good source of K. These should not be applied to the soil surface without controlling the competing vegetation. To do so would stimulate weed growth and create unfavorable moisture stress and light conditions for the seedlings.

For general Christmas tree application, White (1966) recommended the use of complete fertilizers (N-P-K) if no specific deficiency is known. Granular material with an analysis similar to 12-12-12, 12-6-12, or 14-7-7 should be adequate. The 2-1-1 ratio is recommended for soils

of sandy loam or loam texture where N is likely to be the limiting element.

The fertilizers should be placed on the ground in a band at about the edge of the crown but not closer than 8 inches to the central stem. Young trees, 2 to 3 years in the field, should get about 4 ounces. Large trees, 1 to 2 years before harvest, about $\frac{1}{2}$ to 1 pound. White further stated that minor element deficiencies are uncommon in Christmas tree plantations. He suggests that field crop formulations that contain minor elements be avoided, because even very small quantities of boron or other minor elements may be harmful to evergreens.

Jablanczy (1971) urges greater use of lime in Christmas tree culture. Many of the areas used for Christmas trees are cutover areas and abandoned agriculture lands that are usually depleted of their calcium reserve. Liming would help remedy this situation. He cited observations of others as well as his own, made in the Canadian maritime provinces, describing how liming improved needle color and prevented early needle drop of balsam fir, spruce, and pines. M. L. McCormack of the Department of Forestry at the University of Vermont (*personal communication* 1972) has also observed a favorable response in balsam fir to liming in both plantations and natural stands when the soil was brought to a pH of about 6.7.

Turner (1966, 1968, 1968a) conducted fertilizer trials with varying amounts of N, P, K, and S. These were applied in a natural stand of chlorotic 15-year-old Douglas-fir growing on a glacial moraine soil in the Puget Sound Basin. He concluded that Douglas-fir Christmas tree color can be improved and growth controlled by the amount of fertilizer used. Rates of N from 0.125 pounds to 1.0 pounds per tree applied in May effectively improved color by November (fig. 1). Further, these trees exhibited a growth response the following season (fig. 2).

Figure 1.—Nitrogen makes yellow trees greener. November color after May application on Douglas-fir (Turner 1968).

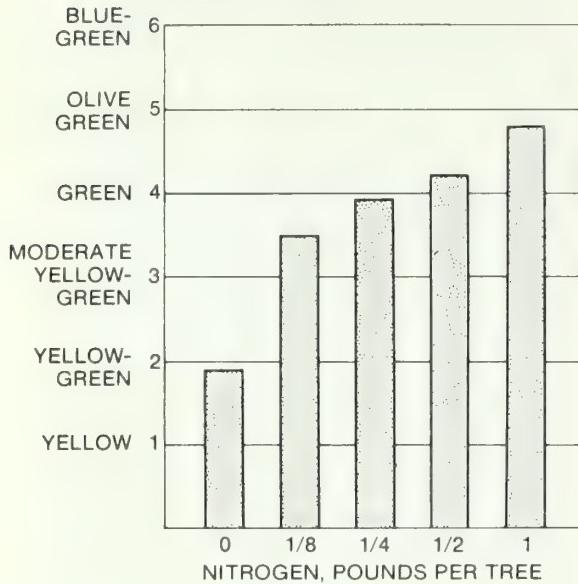
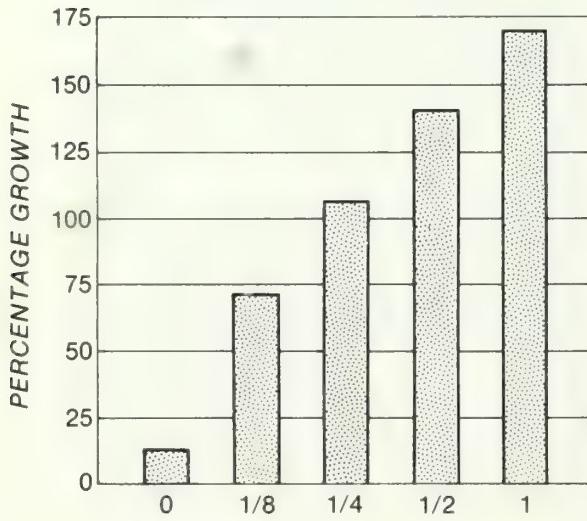


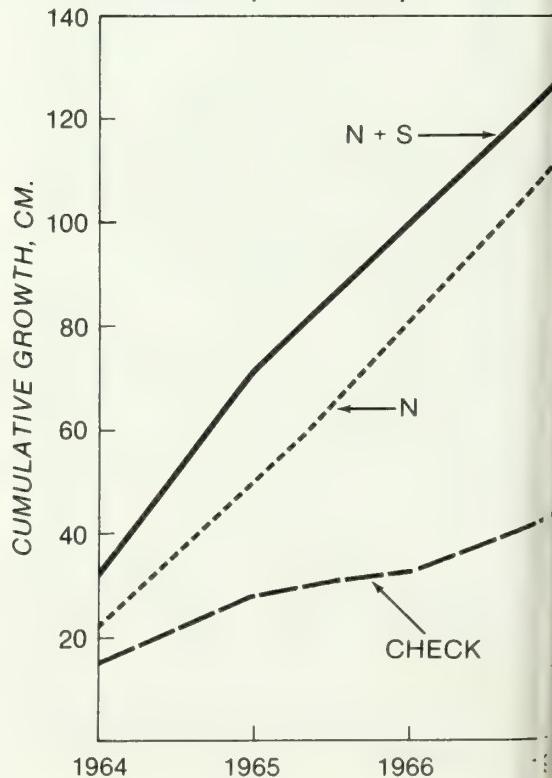
Figure 2.—Nitrogen stimulated leader growth. Percentage growth second season after application on Douglas-fir (Turner 1968).



However, N treatments of more than 0.125 pounds per tree may overextend leader growth. Treatment with P at 0.1 pounds, K at 0.2 pounds, or S at 0.125 pounds per tree had little effect on either color or growth. On the other hand, a treatment of 0.125 pounds of N plus 0.125 pounds of S per tree gave the greatest response in both color and growth rate (fig. 3). For maximum color Turner recommended an application of 0.25 pounds of N per tree in May for harvest in November. But if only growth stimulus is wanted, 0.125 pounds N can be used with safety.

In northern Vermont, fertilizer treatment effects were observed by Kinerson (1967) in three balsam fir plantations. The treatments were: no fertilizer, 1-1/2

Figure 3.—Cumulative growth of Douglas-fir following May 1964 fertilization (Turner 1968a).



ounce per tree 10-10-10 applied to soil surface, and 2 ounces per tree of magnesium ammonium potassium phosphate (7-40-6) probed into the root zone. In two of the plantations, both fertilizer treatments resulted in significantly greater growth. In a third plantation, only the 7-40-6 applications resulted in a significant height growth increase (fig. 4). Generally, the fertilizer treatments increased internodal bud development, height growth, and needle length; in addition they also improved color and reduced winter burn. The root-zone application of slow-release 7-40-6 was judged to be superior to the surface application of granular 10-10-10.

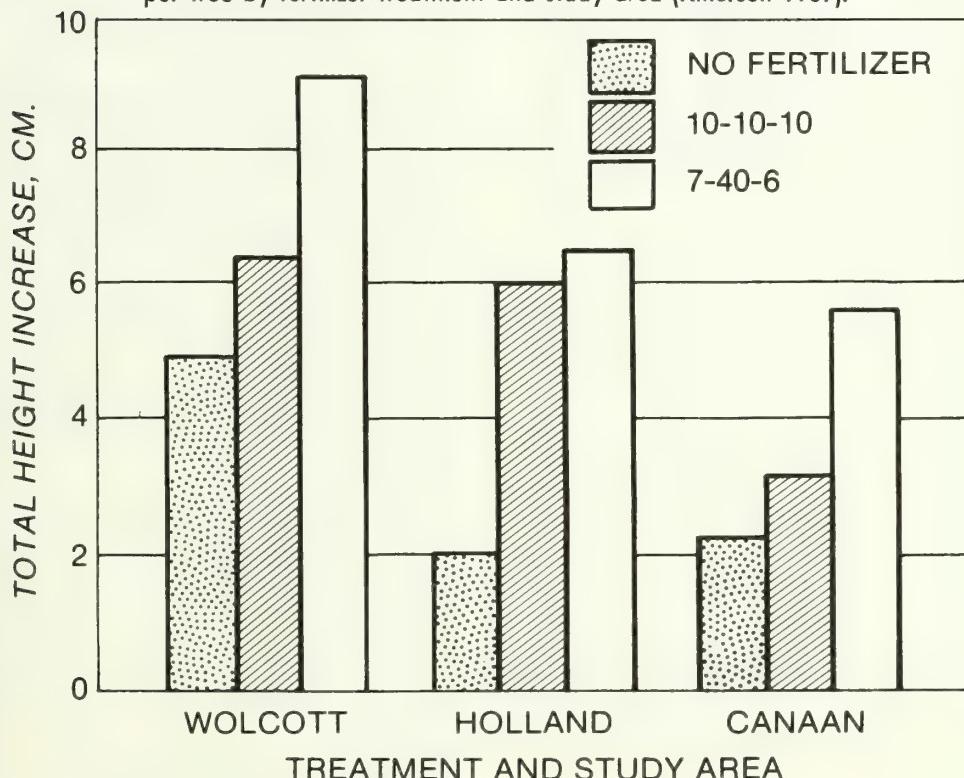
McCormack (*personal communication* 1972) has worked with what he calls a typical Vermont hayfield site, generally heavy soils such as silt loam or clay loam.

Because of past liming practices, their pH is high, averaging about 6.7. In addition, they have a very heavy herbaceous cover. He is attempting to develop cultural techniques specifically for growing balsam fir Christmas trees.

In one trial, he compared three treatments against an untreated control: band spray with simazine at the rate of 12 pounds per acre; 300 pounds each of elemental N-P-K per acre as a complete fertilizer, and a combination of the herbicide and fertilizer treatments. These were evaluated for response in terminal growth, needle color, needle length, and bud formation. The herbicide-only treatment was best, followed closely by the herbicide-fertilizer combination. Significantly poorer was the check, and the poorest was fertilizer only.

In other trials he used a slow-release

Figure 4.—Mean total height increase for 1966 expressed in centimeters per tree by fertilizer treatment and study area (Kinerson 1967).



formulation of 7-40-6. Two ounces per tree in the root zone at planting gave a 3- to 4-year benefit. Initial cost of 7-40-6 was higher than other formulations but the longer term benefits were greater.

Based on his own conclusions and on those of other researchers, McCormack made the following recommendations for growing balsam fir Christmas trees on a Vermont hayfield: (1) the year before planting, band-treat the site with 14 pounds simazine per acre; (2) the following year plant big rugged 2-3 transplants in a big hole; (3) place 2 ounces of slow-release 7-40-6 in the planting hole; (4) about 2 years after planting, treat each tree with 4 ounces of 15-15-15; and (5) maintain weed control. He strongly emphasized that fertilizer without weed control is a total loss.

The published results of Christmas tree fertilization research are not very plentiful. Some of the general forest-fertilization results have application and give helpful data. But there is certainly a lack of designed research on Christmas tree fertilizer techniques. One reason is that the data are difficult to analyze. For instance, increased height growth is good, to a point; beyond that too much growth is detrimental. Also, many of the characteristics of a high-quality tree are subjective, and an accurate description is elusive. How do you analyze differences in needle color, crown density, and needle length? After all, beauty is in the eyes of the beholder and is very difficult to assign a numerical value to.

There is little doubt that fertilization can and does have importance as a technique in intensive Christmas tree culture. This is borne out by the observations of improved tree quality and shortened rotation as a result of fertilizer treatments. Evidence shows the economic soundness of fertilizers because of increased returns on investment. It now remains to develop methods for determining and applying more accurate prescriptions of fertilizer formulation.

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ESTABLISHING FOREST ON SURFACE-MINED LAND AS RELATED TO FERTILITY AND FERTILIZATION

by MIROSLAW M. CZAPOWSKYJ, *Principal Soil Scientist,
USDA Forest Service, Northeastern Forest Experiment
Station, Kingston, Pa.*

ABSTRACT. Studies on establishing forest on strip-mined lands show that most spoils are not hostile to planted trees. Nearly all essential elements for plant growth were found in the spoils; their concentrations depend on lithology, acidity, and the rate and degree of spoil weathering. Planted and seeded forest trees respond strongly to application of N and P both singly and in combination. Certain spoils will respond to K application. Extreme acidity and high concentrations of Mn, Fe, Zn, S, and Al are major factors limiting plant growth on coal-breaker refuse; but such areas are a small portion of the total area of disturbed land. Application of lime alleviates these problems.

ON LAND that has been drastically disturbed by mining coal, iron ore, clay, sand, and other natural resources, natural vegetation comes back very slowly—if at all. To create a new forest on these lands means planting forest tree seedlings or sowing the seeds. In our search for ways to establish a forest, we are concerned with the natural supply of nutrients essential to plant growth, and with the possibilities of applying lime, fertilizers, and other amendments.

BACKGROUND

Disturbance of land by strip and surface mining of natural resources has become common worldwide. Because strip-mined lands contribute to an overall deg-

radation of the environment, they have become a matter of great concern in many countries and states.

Eastern North America is fortunate in having a wealth of natural resources. The Atlantic Seaboard has extensive deposits of gravel and fine sand, the latter essential in the glass industry. Other regions are rich in iron ore, phosphates, and kaoline clay deposits. Interspersed within the massive rock formations of the Appalachian Mountain chain are the world's finest deposits of coal.

From Florida to Maine, these resources have been mined. Now the drastically disturbed lands are a significant component of the landscape. Perhaps the most significant of all is the Appalachian Mountain region, which has had more

than its share of surface-mining operations.

As of 1965, there were 3,357 square miles of strip-mined lands in 26 states east of the Mississippi River. Seventy percent of these lands were disturbed by strip-mining for coal, and an area approximately the size of the State of Delaware now needs rehabilitation (USDI 1967).

On the spoil material, re-establishment of natural vegetation is a very slow process. The bare spoils in many places cause serious environmental problems—and in some places ecological disasters. Adjacent land, water, forests, and aesthetics are drastically affected.

Although tree planting on strip-mined lands is as old as strip-mining itself, it was not until after World War II that a number of experimental tree plantings and pastures were established on those lands throughout the East. Now tree planting is required by law in each state.

The majority of studies on establishment of new forests on disturbed lands can be grouped as follows: (1) suitability of the tree species to the site; (2) planting seasons and methods; (3) effects of grading on tree performance; (4) seeding—direct, aerial, and hydroseeding; (5) performance of grasses and legumes as nurse crops for trees; and (6) performance of trees as related to fertilization, liming, and mulches.

Future reclamation and rehabilitation practices on disturbed lands will be geared toward diversified land use, including agricultural, horticultural, industrial, commercial and residential development, and recreation. However, the establishment of new forests will remain the major reclamation practice.

STRIP-MINED LANDS AS SITES FOR NEW FORESTS

Strip-mine spoils are composed of unstable debris in a heterogeneous mixture from all strata that were present in the

overburden. This material exhibits great diversity in its physical, mineralogical, and biological characteristics and differs in the supply of mineral nutrients needed to sustain plant life.

Studies show that nearly all essential elements are found in most of the overburden. Concentrations are variable, depending on the lithology, spoil age, degree and rate of weathering, and erosion processes. Unfortunately, organic matter is practically nonexistent.

Results from many studies conducted in the bituminous and anthracite coal regions (*Hart and Byrnes 1960, Limstrom 1960, Chapman 1967, and Czapowskyj 1970*) indicate that certain soils will support excellent forest plantations without any site preparation or soil ameliorants. On the other hand, some soils may require site preparation such as grading, terracing, and harrowing. Obviously the effects of grading vary with the soils. Limstrom (1952, 1960) and Chapman (1967) reported that in the Central States compaction resulting from spoil grading has adverse effects on tree establishment on soils derived from limestone and having high content of clay. Compaction of soils, besides reducing air and water infiltration, results in a less available supply of essential elements and a reduced biotic life.

However, Finn (1952) reported that white ash (*Fraxinus americana L.*) and yellow-poplar (*Liriodendron tulipifera L.*) grew equally well on graded and ungraded spoils in Ohio derived from sandstone and shales, and that growth was significantly better only on ungraded soils derived from limestone. No marked differences in foliar N, P, and Ca between graded and ungraded soils were noted.

Studies in Pennsylvania (*Czapowskyj 1970*) indicated that coarse-textured anthracite spoils were improved by the degree of compaction from grading operations. There is evidence that the Ca, Mg,

and K in graded spoils in three of four spoil types were considerably higher than in their ungraded counterparts.

Other spoils in this region are plantable; but soil amendments such as lime, fertilizer, mulch, or seeding nurse crops are prerequisite for successful plantations.

Finally, considerable acreage is unsuitable for tree growth because of stoniness, texture, and stability of slope. These conditions cannot be corrected by liming, fertilizing, or mulching. Such spoils are unique problems.

Considerable work has been done on evaluating the performance of established plantations as related to spoil characteristics. Although past research has had some impact in generating interest in spoil classification, fertility, acidity, and nutrient availability to plants, the disturbed lands have in general received little attention by soil scientists.

STATUS OF NUTRIENTS AND RESPONSES TO FERTILIZERS

In a number of reports dealing with establishment of forests on strip-mined land, estimates have been made of natural fertility and nutrient availability to plants. These have been related to spoils of different physical, chemical, and biological characteristics in various states

and climatological regions. Consequently, workers differ in their evaluation of plant nutrient status from one area to another.

In studying these reports, I found that N, P, and K are the most frequently mentioned limiting elements for plant growth. Table 1 shows examples of the supply of natural nutrients in selected spoils. The data were compiled from reports of several investigators (*Barnhisel and Massey 1969, Stiver 1949, and Czapsowskyj 1969 and 1970*). Unfortunately, literature on the responses due to added fertilizers is meager, and the responses are expressed primarily in early survival and height growth.

Macronutrients

Many investigators (*Schramm 1966, Struthers 1960, Stiver 1949*) and others have concluded that coal-mine spoils are deficient in N. The fact that the spoil in many places will support an excellent growth without adding N is attributed to the N supplied by rainfall and biological fixation. On the other hand, Cornwell and Stone (1968) said that the N levels in certain anthracite spoils are not critical, at least in black shale spoils.

Cummings et al (1965) reported that certain Kentucky spoils have low concentrations of soluble salts and organic matter, abundant Mg, but low exchangeable

Table 1.—Main nutrient contents of some coal-mine spoils

Spoil	pH	N pct.	P p.p.m.	K m.e./100 gm.	Ca	Mg
KENTUCKY—BITUMINOUS						
Shale—black	2.2	—	—	<0.1	1.0	2.3
Shale—gray	5.0	—	—	0.8	5.5	4.8
Shale—gray	6.2	—	—	0.6	8.6	4.2
INDIANA—BITUMINOUS						
Sandstone	4.0	<0.1	16.6	<0.1	1.8	0.6
Shale—gray	4.7	<0.2	6.6	<0.1	3.5	1.5
Glacial till	7.3	<0.1	15.6	0.1	17.5	3.5
PENNSYLVANIA—ANTHRACITE						
Breaker refuse	2.9	<0.1	10.7	0.4	3.2	0.3
Sandstone	6.3	0.1	41.9	0.2	2.9	0.3
Glacial till	7.1	<0.1	64.2	0.2	2.4	0.4

Ca. Available K and P are low to adequate. Low to moderate concentrations of available P in extremely acid strata in Kentucky were reported by Berg and May (1969). But Grandt and Lang (1958) found available P to be very high and K high in many spoils in Illinois.

May et al. (1969) observed that within a small segment of kaolin-mining spoils there are extreme variations in physical characteristics and concentrations of nutrient elements. The spoil may contain from 0 to 100 percent of sand or 0 to 85 percent of clay. Available P and exchangeable K, Ca, and Mg range from 2 to 160, 4 to 110, 6 to 600, and 2 to 600 p.p.m., respectively. Ca and Mg are generally low except where lime material is present. P and K are low in all strata. Mn and Fe are most abundant in the upper strata.

May et al. (1969) conducted greenhouse and field fertility experiments on kaolin-mine spoils in Georgia and South Carolina and found that by using 810 pounds of lime, 12 pounds of N, 28 pounds of P, and 20 pounds of K per acre, an excellent cover of grasses and lespedezas was established. Most promising tree species were loblolly pine (*Pinus taeda* L.), Virginia pine (*Pinus virginiana* Mill.), sycamore (*Platanus occidentalis* L.), sawtooth oak (*Quercus acutissima* Carr.), and black alder (*Alnus glutinosa* L.) Gaertn.). It was observed that initial growth was poor and foliar symptoms of nutrient deficiencies were very evident when N and P were not applied at time of planting. Lime and K did not produce a measurable response the first year. Without fertilization, even first-year mortality was high.

Troth (1971) studied the concentration of several essential elements in foliage of young sycamore, loblolly pine, and slash pine (*Pinus elliottii* Engelm.) after these trees had received a variety of N, P, and K fertilizer treatments. It was suggested that application of N, P, and K each improved early growth of slash

pine where spoil nutrient levels were low. The best growth of sycamore and loblolly pine was associated with N concentrations of 1.6 and 1.4 percent, respectively, in September foliage. Evidently on many sites P and K do not limit tree survival and growth in the early stages.

Certain reports show that in applying fertilizers on strip-mined lands, one is not free from the risk of reducing germination or tree survival.

A study by Thomas (1966) suggested that survival of tree species was generally better on unfertilized plots than on fertilized plots and that the best height growth was obtained where N-P-K or N-P-K + Ca was applied.

Bengtson et al. (1969) conducted greenhouse experiments in northeastern Alabama, using spoils as media for seedling loblolly pine. They found that the seedlings responded dramatically to complete fertilizer and that the response was enhanced when microbial inoculum of fresh pine duff was added. N and P were found to be the only inorganic nutrients (macro or micro) limiting pine growth.

A further evaluation was made of the effects of concentrated superphosphate and several N-P fertilizer mixtures applied at time of seeding. Concentrated superphosphate, 50 pounds P per acre, when broadcast with the seed on the spoil surface, had no significant effect on germination or early seedling growth. On the other hand, the application of uncoated urea and diammonium phosphate greatly reduced germination even at the rate of 50 pounds N per acre. At this rate sulfur-coated urea ammonium polyphosphate, monoammonium phosphate, ammonium nitrate, and ammonium nitrate phosphate did not reduce germination. All N-P combinations increased early growth of seedlings.

Zarger et al. (1969) suggested that nitrogen and phosphorus are the main elements limiting growth of loblolly pine on coal mine spoils in Alabama. Early results showed a significant increase in

seedling height when P was applied at 100 pounds per acre. Additional growth and improvement in seedling color and vigor were noted when N was applied with P and N rates of 25 and 100 pounds.

Seeded pines also responded strongly to N-P fertilizer applied at rates of about 100 pounds per acre of each element. Fewer seedlings were killed by frost-heaving when the spoils were fertilized.

Funk and Krause (1965) reported on 11 species of trees planted on Ohio strip-mine spoils with pH 5-7. Some were fertilized with pellets containing 28 percent N and 5 percent P_2O_5 . After 2 years the fertilized American sycamore, European alder, and yellow-poplar were significantly taller than those that were not fertilized. However, fertilization significantly reduced yellow-poplar survival. Seven other species in the planting were less affected by fertilization. The authors concluded that properly timed applications of appropriate N-P fertilizers to planted or seeded pine or pine-grass mixtures are the key to rapid establishment of productive vegetation on this and similar sites.

Vogel and Berg (1969) showed that phosphorus is a limiting element in many coal mine spoils in eastern Kentucky for the early growth of direct-seeded black locust (*Robinia pseudoaccacia* L.). By fertilizing with 44 pounds per acre of P, the first year's height of seedlings was increased fourfold, and higher P rates produced even greater growth. Adding N with the P also caused some additional increase in height. Warm-season herbaceous species seeded with the locust were less competitive with the locust seedlings than were cool-season species.

Micronutrients

The status of micronutrients in spoil materials has been reported by numerous workers. However, they were studies primarily in connection with spoils of high

acidity and phytotoxicity. Barnhisel and Massey (1969) pointed out that contents of available Fe, Mn, and Zn in eastern Kentucky spoils approach toxic levels and pose a serious problem in the establishment of vegetation. Berg and Vogel (1968) reported the occurrence of Mn toxicity on six legumes grown in 46 acid strip-mine spoils from Kentucky. Toxicity was characterized by a distinct paling (chlorosis) on the leaf margins, which was readily seen on young leaves of all the species except Kobe lespedeza (*Lespedeza striata*) (Thunb.) H. & A.). It was pointed out that spoil pH was useful in prediction of Mn toxicity on these legumes and that the water-soluble Mn extracted from the spoil was not.

Cornwell and Stone (1969) studied the availability of plant nutrients for five spoil types in the Anthracite Region of Pennsylvania. Eleven elements, including certain micronutrients, were determined. It was observed that foliar concentrations of all elements except Cu differed significantly among spoil types. Gray birch (*Betula populifolia* Marsh.) accumulated Zn to 400 p.p.m. and Mn to 1,500 p.p.m. without evidence of Zn, Mn, B or Al toxicity. Gray birch is exceptionally tolerant to acidity and to high concentration of these elements.

LIME—RATES AND RESPONSES

Acidity and phytotoxicity are probably the major causes of mortality or poor survival and growth of vegetation. Toxic conditions are due primarily to high concentrations of sulfur present in pyritic shales and rejected coal. Fortunately, except for coal-breaker refuse, toxic strip-mine spoils are not widespread. The applications of lime or lime materials would alleviate most exceptional cases.

Lime and lime materials are the oldest and the cheapest soil amendments. The benefits of lime in agriculture and in intensively managed forest has been ade-

quately documented in scientific literature.

Lime has many functions in soil. It is used primarily to adjust the base saturation on the exchangeable complex of soil colloids, neutralizing the excess acidity and inhibiting the availability of elements present at toxic concentrations. It supplies the elemental Ca and Mg, the latter present in dolomitic limestone. Changes in soil acidity, brought about by liming the spoil, affect the availability of P and of micronutrients in the soil and create a better environment for microorganism activity. Lime is naturally the most logical amendment to be added to coal-mine spoils, especially those of extremely low reactions, if the establishment of suitable vegetation for forest, pasture, lawn, or golf green is to be accomplished.

Grandt and Lang (1958), while studying the neutralization of acidity of certain spoils in Illinois, found that some spoils required 40 to 70 tons of limestone per acre to bring the pH of the yellow shale spoils up to and above neutrality.

Tyner et al. (1948) and Tyner and Smith (1945) reported that 5.0 tons per acre of CaCO_3 added to strongly acid spoils in West Virginia was all that was necessary to establish legumes and grasses on this media. However, on certain spoils the acidity reverted to toxic levels (pH 3.0) within 60 days.

Ramsey (1970) reported an excellent stand of grass on highly acidic bituminous coal-breaker refuse after adding and incorporating agricultural lime equivalent to 40 tons per acre along with 1,500 pounds per acre of 6-24-24 fertilizer.

There is recent evidence that lime is an essential amendment in the establishment and improved growth of tree seedlings. Plass (1969) concluded from greenhouse trials that liming extremely acid strip-mine spoils at the rate of 5.0 tons per acre-foot significantly increased the growth of pine seedlings. Apparently growth rate may be related to the reduc-

tion in concentration of metallic ions of Mn, Fe, Cu, and Zn.

In the Anthracite Region of Pennsylvania, lime was applied at the rate of 2.5 and 5.0 tons per acre to coal-breaker refuse, and crownvetch (*Coronilla varia*, L.), red pine (*Pinus resinosa*, Ait.), and Japanese larch (*Larix leptolepis*, Sieb and Zucc, Gord.) were planted. It was found that lime applications were essential for adequate survival and establishment of crownvetch (Czapowskyj et al. 1968) and both forest species.

Since the question arose as to the duration of lime effect, it was decided to study this aspect also. It was found that the lime brought the surface layer—0 to 3 inches—to near neutral pH within a year. This surface layer was still neutral 7 years after liming. The effects of lime were detectable to a depth of 9 to 12 inches only about 6 years after lime application, and the lower liming rate—2.5 tons per acre—was as beneficial as the higher rate—5.0 tons per acre (Czapowskyj and Sowa 1972). Evidently 2.5 tons is adequate to neutralize the refuse to establish vegetation.

CONCLUSIONS

In the reclamation of strip-mine spoils for the establishment of forest as related to natural fertility and the responses to fertilization, the following generalizations can be made:

- Establishment of a forest, as in the past, will remain the major reclamation practice of strip-mined lands.
- Establishment of natural vegetation is a slow process, and tree plantings and seeding are the major forest-establishing practices.
- Most strip-mine spoils are not hostile to planted trees. Areas of extreme acidity and acid-related phytotoxicities are not widespread except on coal-breaker refuse.

- Nearly all essential nutrients are present in most of the spoils. Their concentrations vary, depending on the lithology and the weathering rate.
 - Strip-mine spoils are practically devoid of organic matter, the major nutrient supplier, especially N.
 - Nitrogen and phosphorus are the main elements deficient for plant growth. Magnesium and potassium content is usually adequate.
 - Supply of micronutrient Mn, Zn, Cu, and S range from toxic levels in extremely acid spoils to adequate in moderately acid spoils.
 - Plantations fertilized with N, P, and K fertilizers on kaoline spoils and with N and P on coal-mine spoils—singly or in combinations—show a definite positive response in height growth, vigor, and color.
 - The effects of fertilization are not entirely free from the risk of reducing tree survival. It depends on tree species, timing of application, fertilizer formula, and the degree of nutrient release. Slow-release fertilizers have a special place in fertilizing surface-mined lands.
 - Liming of extremely acid spoils to supply elemental Ca, to reduce and alleviate the toxicity of micronutrients and Al present, has a definite place in forest establishment.
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FERTILIZER NEEDS AND TREATMENT RESPONSES FOR WOOD FIBER PRODUCTION: FIELD ASSESSMENT

by DONALD L. MADER, *Professor, Department of Forestry and Wildlife Management, College of Food and Natural Resources, University of Massachusetts, Amherst, Mass.*

ABSTRACT.—Successful use of fertilizers depends on (1) accurate assessment of inherent productivity potential of the site, (2) determination of nutrient status and needs on the site, and (3) accurate prediction of response to increments of fertilizer added. Site potential can be determined by site index or other stand measures, or by soil-site studies. Nutrient status and needs can be assessed by visual symptoms, foliar analysis, or soil analysis. Visual symptoms coupled with foliar analysis have been effective in identifying severe deficiencies, but ability to diagnose needs on better sites or predict response on any site is lacking. Soil analysis has not been developed successfully for diagnosis of needs or responses. Extensive test-plot studies for various sites are needed to provide information for developing foliar or soil-based diagnostic systems.

IT IS EASY to talk in glowing generalities about forest fertilization, to point with pride to the successes of experiments in the South, the Northwest, and Canada, and to give the practising forester visions of highly fertilized super-trees producing wood fiber and profits like some fabled horn of plenty. Alas, the forester must deal not with visions, but with real stands of trees. They are not about to tell him that their mineral nutrition is sub-par and that a good dose of salts would make them perform better. So it is the forester or consulting forest-soils specialist who must ask the ques-

tions, do the probing, diagnose whether treatment is advisable, prescribe the treatment, predict the results, and take the credit or blame for what happens.

In the simplest terms, a diagnostic system to assess fertilizer needs for wood-fiber production requires three things:

- A means of assessing inherent growth potential of various sites.
- A means of assessing fertilizer needs versus other limiting growth factors.
- A prediction system for estimating growth response to a particular increment of added fertilizer.

If we can measure the growth or potential growth accurately, if we can assess the nutrient status effectively, and if we can predict the response to fertilizer treatment, then, and only then, can we analyze whether the economic or other benefits are sufficient to justify the treatment. So the questions are: What is the best way to put such a diagnostic system together for field operation? Do we have the information for diagnostic systems for various species and sites? If not, what are we lacking, and what should we be doing about it?

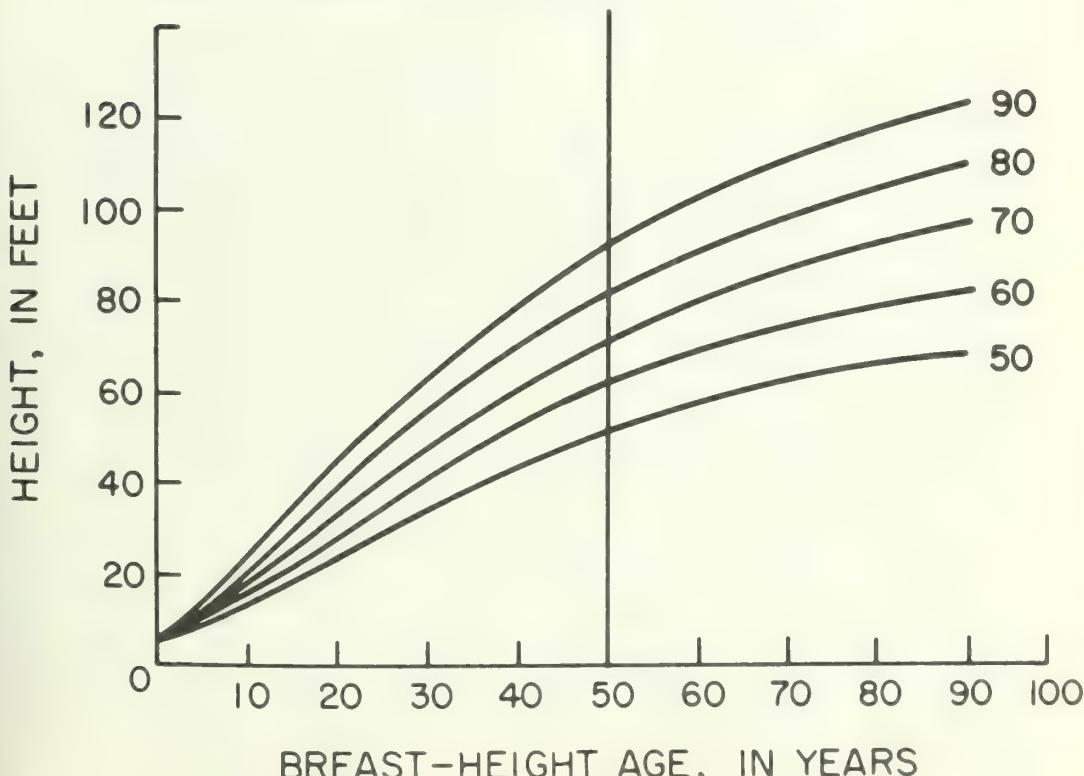
We are fortunate in having several models of diagnostic systems for fertilization that are used in agriculture, and we can draw on considerable information about their good and bad points seen over long periods of time.

TO ASSESS GROWTH POTENTIAL

The first problem, to assess growth potential within a site-classification system, is certainly not new to the forester. It is one of his basic steps in timber management. Anyone growing a longterm crop such as trees needs to know at what rate he is producing or could produce on a particular site. Field observation of poor growth rates often is the first clue that tree nutrition is not adequate.

Growth rates can be measured and evaluated in several ways. (Gessel *et al.* 1960). Determining of the site index for a stand is the most common method of estimating relative productivity for different sites. Site index for a species is the average height of dominant and codominant trees, not suppressed during their

Figure 1.—Site-index curves for eastern white pine in New England (breast-height age 50) based on Frothingham's site-index curves corrected to a breast-height age of 50. (Leak *et al.* 1970.)



growth, at a standard age—usually 50 years in the East. In actual practice, heights of about 10 dominants and co-dominants are measured, their ages are determined, and average values are computed. Then the age and height intersect is plotted on a standard set of site-index curves such as those for white pine (fig. 1), which are average curves of heights at different ages for the different site-index values (*Leak et al. 1970*). Thus the site-index value for the site can be determined by the plotted position in relation to the standard curve.

For the site-index curves, we generally also have sets of curves or tables giving cubic-volume growth for the site-index levels, as in table 1 (*Leak et al. 1970*). In general we do have good site-index curves and associated cubic-volume pro-

ductivity tables for most of our species in the Northeast.

Sites with very low-productivity potential can be identified as possible candidates for improvement through fertilization. Unfortunately sites that may respond to fertilization are not limited to low-productivity areas; in fact, absolute response and profitability are often greater on better sites (*Baule and Fricker 1970*), so some other method of identifying such areas is needed.

A 5-year intercept, proposed by Wakeley and Marrero (1958) and Ferree et al. (1958), is a second method of using height to evaluate growth and site productivity. Average 5-year height growth from breast height upward is determined and can be related to conventional site-index values (fig. 2) (*Richards et al.*

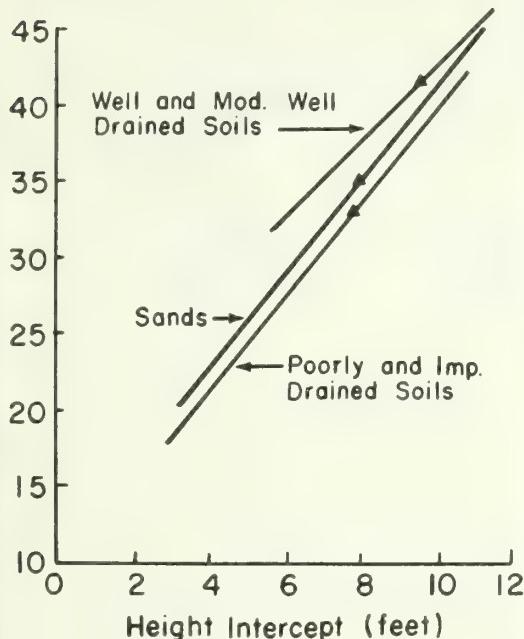
Table 1.—Cubic-foot yields per acre to a 3.0-inch i.b. top in Maine, Massachusetts, and New Hampshire, by age, site index (b.h. page 50), and stocking percent.

[Applies to overstory pine trees 3.0 inches d.b.h. and over.]

Age (yrs)	Site index	Stocking percent									
		40	50	60	70	80	90	100	110	120	130
20	50	761	931	1,098	1,262	1,423	1,583	1,741	1,897	2,052	2,206
	60	892	1,090	1,286	1,477	1,667	1,854	2,039	2,222	2,403	2,583
	70	1,044	1,277	1,506	1,730	1,952	2,171	2,387	2,602	2,814	3,025
	80	1,223	1,496	1,763	2,026	2,286	2,542	2,796	3,047	3,296	3,543
	90	1,432	1,752	2,065	2,373	2,677	2,977	3,274	3,569	3,860	4,149
40	50	1,886	2,307	2,719	3,125	3,526	3,921	4,313	4,700	5,084	5,465
	60	2,209	2,702	3,185	3,660	4,129	4,592	5,051	5,504	5,954	6,400
	70	2,587	3,164	3,730	4,287	4,836	5,378	5,915	6,446	6,973	7,495
	80	3,029	3,075	4,368	5,020	5,663	6,298	6,927	7,549	8,166	8,778
	90	3,548	4,339	5,115	5,879	6,632	7,376	8,112	8,841	9,563	10,280
60	50	2,552	3,121	3,680	4,229	4,771	5,306	5,836	6,360	6,879	7,395
	60	2,989	3,656	4,309	4,953	5,587	6,214	6,834	7,448	8,057	8,660
	70	3,500	4,281	5,047	5,800	6,543	7,277	8,003	8,722	9,435	10,142
	80	4,099	5,014	5,910	6,793	7,663	8,523	9,373	10,215	11,050	11,878
	90	4,800	5,871	6,922	7,955	8,974	9,981	10,977	11,963	12,940	—
80	50	2,968	3,631	4,280	4,919	5,550	6,172	6,788	7,398	8,002	8,602
	60	3,476	4,252	5,013	5,761	6,499	7,228	7,950	8,664	9,372	10,074
	70	4,071	4,980	5,871	6,747	7,611	8,465	9,310	10,146	10,975	11,798
	80	4,768	5,832	6,875	7,902	8,914	9,914	10,903	11,882	12,853	—
	90	5,584	6,830	8,052	9,254	10,439	11,610	12,769	—	—	—
100	50	3,250	3,976	4,687	5,387	6,077	6,758	7,433	8,100	8,762	9,419
	60	3,806	4,656	5,489	6,308	7,116	7,915	8,704	9,486	10,262	11,031
	70	4,458	5,453	6,428	7,388	8,334	9,269	10,194	11,110	12,018	12,918
	80	5,221	6,386	7,528	8,652	9,760	10,855	11,938	—	—	—
	90	6,114	7,478	8,816	10,133	11,431	12,713	—	—	—	—

Source: *Leak et al. (1970)*.

Figure 2.—Relation of attained site index to height intercept for 112 plots. (Richards et al. 1962.)



1962), or directly to productivity. Wilde (1964) proposed an H/I ratio, consisting of the average yearly tree-height growth divided by the average yearly growth of the 5-year intercept, to assess growth patterns (fig. 3). He suggested that a very low value for stands 20 to 40 years old usually indicates a need for fertilization or other site improvement.

These intercept methods are applicable only to trees with identifiable yearly internodes, particularly pines; and site-index curves and associated cubic volume based on them are available for only a few species in the Northeast, red pine being one of them (Richards et al. 1962).

Cubic volume production in fully stocked stands can be measured directly with varying degrees of accuracy, depending on whether stem analyses or standard volume tables are used. My own work suggests that a 5-year volume growth period may be a suitable, though certainly more difficult, means of evaluat-

ing cubic-volume productivity than site index (Mader 1963).

The concept of current site index (Heiberg and White 1956) may be an important one for fertilization problems, because the state of nutrition and growth may change considerably over the long-term age span of stand development. Measurement of recent periodic height or volume growth can be used to assess this; however, as yet the normal changes in both of these variables in relation to age are not well documented or available for making comparisons.

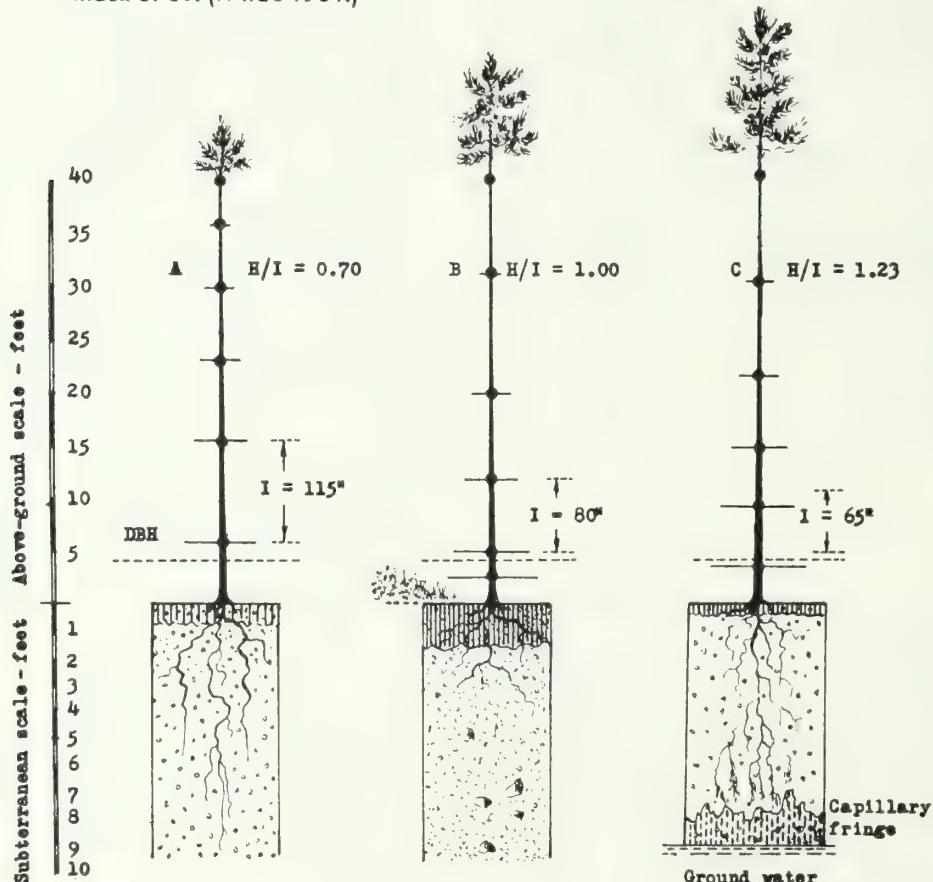
The other major approach to assessing site-productivity potential, as opposed to some measure of tree growth, is through site-factor measurements or soil-classification units that have been correlated with productivity. Such studies have been made for a number of species in various parts of the Northeast. The accuracy of predicted potential growth varies a great deal from study to study, depending on factors measured to serve as a basis of prediction or the uniformity of soil series when they are the basis.

TO ASSESS NEEDS

The second component of the diagnostic system is assessment of fertilizer needs; that is, the nutritional status of the stand and site, particularly whether severe deficiencies are present. Foresters until recently have suffered in the development of diagnostic information and techniques because of the prevailing attitude that trees required small amounts of nutrients, that such supplies could be developed and maintained by careful management of the vegetation, and that fertilization as a general practice was uneconomic.

Toumey and Korstian (1947) said, "The amounts of essential mineral constituents in the soil and the amounts used by forest vegetation are such that even soils low in them contain an excess. . . . He (a farmer) maintains and in-

Figure 3.—Growth patterns of red pine plantations imparted by environmental conditions. A, Progressively declining height growth retarded by inadequate supply of water and nutrients in a soil with an infertile substratum. B, Progressively accelerated growth on a fertile soil resulting from a suppression of weeds by the closed canopy. C, Explosively increasing growth caused by a contact of roots with ground water. Horizontal lines mark 5-year growth periods. All three plantations at the age of 30 years exhibited the same site index of 59. (Wilde 1964.)



creases soil fertility largely by artificial means, a forester through the medium of his crop of trees." Similar thoughts that physical properties of soils are of paramount importance compared to nutrients are expressed by Lutz and Chandler (1946) and by Coile (1952).

Historically, most of the cases of successful diagnosis and treatment of nutrient deficiency in forestry resulted from observation of poor growth, vigor, and

appearance of forest stands and attempts to find out why the stands were in such debilitated condition. Here we had the emergence of the simplest diagnostic system, one that will function where severe deficiencies prevent normal healthy growth. Identification of the problem as a nutrient deficiency involves one or all of the following:

- Abnormally slow growth compared to other stands or site-index tables.

- Abnormal appearance of foliage, often coupled with twig dieback, etc.
- Lack of other evident problems such as insects or disease.

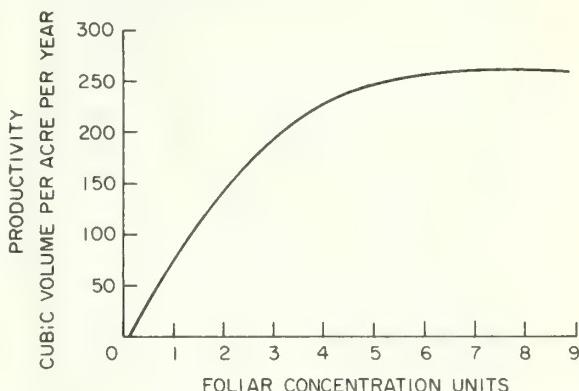
Fertilizer test plots including all major elements or selected ones based on interpretation of the foliage symptoms are then set up and the trees are observed to see if color, vigor, and growth are improved by any particular nutrient element. Once a deficiency of an element is identified, test plots can be set up to see how much fertilizer is needed to get maximum response on that site.

Unfortunately, this system, though sufficient for solving a particular problem, does not provide a general frame of reference. The nutrient status or potential responses of stands of normal growth and appearance are ignored, even though they may be economically more feasible to fertilize (*Baule and Fricker 1970*). No mechanism for predicting response on other sites is developed, and even the possibility of response to other nutrients after correction of the primary deficiency may be overlooked without extensive well-designed plot tests.

A more general and precise diagnostic system can be developed through foliar analysis or soil analysis, or a combination of the two, the techniques of which are discussed in another paper. The general assumption in foliar analysis is that, below a critical value or range, as the nutrient concentration in the sensitive plant tissue decreases, a progressively more severe deficiency develops, with accompanying greater reductions in growth. Above the critical levels, it is assumed that supplies of the element are sufficient and that no growth response to additions will occur although tissue concentration may increase (*Stelly 1967*).

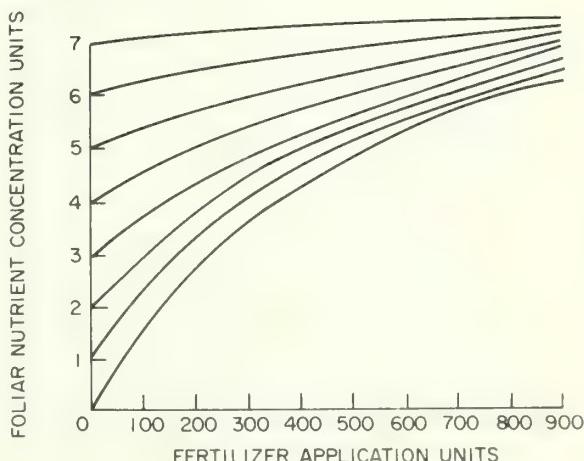
An idealized diagnostic system based on foliar analysis would operate as follows. We would first measure foliar nutrient concentrations on a wide range of stand productivity and nutrient status to

Figure 4.—Hypothetical curve relating foliar nutrient concentration to forest stand productivity potential.



develop a curve of the type in figure 4 to identify the critical levels. Stone *et al.* (1958) presented a curve of this type relating foliar K and current site index. Then through a series of fertilizer test plots we would determine the growth response and foliar nutrient change after additions of a particular nutrient at several rates, enabling us to develop a set of curves relating fertilizer application to foliar content (fig. 5).

Figure 5.—Hypothetical curves relating fertilizer application rates to foliar nutrient response.



At this point such a theoretical system would become operative. We could analyse foliage from a stand, see where it falls on the productivity curve and how much increase we could achieve from a particular fertilizer application, and decide whether the application is worthwhile. Unfortunately, in reality the relationships are not that simple. Where only one nutrient is limiting and levels are very low, such a straightforward relationship might hold. But the evidence is that at one foliar level of a particular nutrient both inherent growth and response vary because of differences in levels of other nutrients or other factors such as moisture. That is, we are dealing with a multiple limiting factor system rather than a single limiting factor.

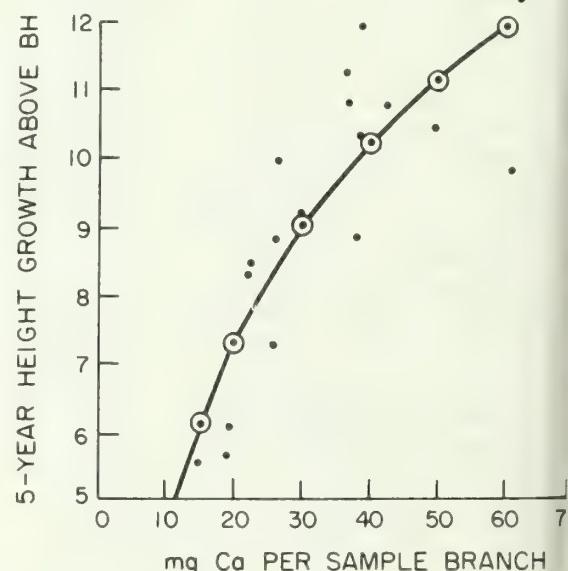
We have barely scratched the surface of this problem. One approach to a solution would be to segregate sites into several classes on the basis of foliar nutrient regime similarities or soil type similarities and then study productivity and growth responses of the subgroups. As yet we have not had extensive enough site investigations or fertilizer plot studies to predict the success of this approach; however, it seems likely that such narrowing of the variation of initial units would greatly enhance prediction of response. Mitchell and Chandler's (1939) early work on N fertilization of hardwoods in the Northeast indicates that the N-supplying capacity of different sites and the foliar response to different application levels can be put on a common base, but that the response in growth on different sites cannot be coordinated readily.

STUDY APPROACHES

A second approach is through some sort of general multiple-regression model including foliar nutrients, and other variables if required, so that the effects of multiple limiting nutrients or other factors can be taken into account at the

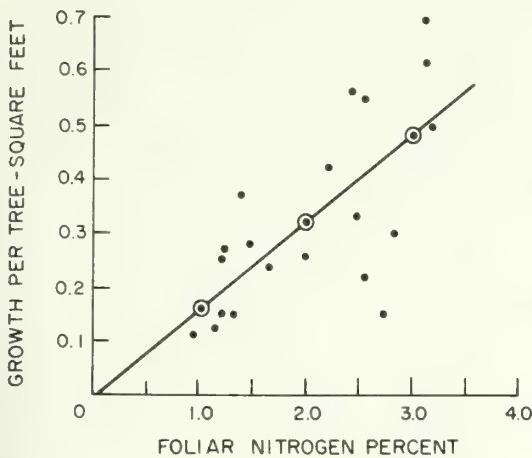
same time. The feasibility of this system is uncertain, but it has some promise. We have carried out two studies in which we have made multiple-regression analyses of different growth measures relating to foliar nutrient measures. In one study (*Hoyle and Mader 1964*) 5-year intercept site-index values were found closely related to either total Ca in the needles of the sampled branch or percent Ca in the foliage (fig. 6). Addition of other nutrients increased the effectiveness of prediction only slightly.

Figure 6.—Relationship between mg Ca per sample branch and 5-year height growth intercept above breast height in red pine. Equation: $HT = 5.33 + 9.69 \log_{10} \text{mg Ca}$, $R^2 = 0.73$.



In another study (*Thompson 1969*) in which foliar nutrients of sugar maple were studied, the results showed a significant correlation between N content of leaves and basal-area growth rate (fig. 7), accounting for about 50 percent of the variation in growth. A multiple-regression equation including Ca, K, and

Figure 7.—Relationship between foliar N and basal-area growth rate in sugar maple. Equation: $BA = - .00017 + .01616 (\% N)$, $R^2 = 0.49$.



Mg accounted for almost 70 percent of the variation in growth (fig. 8). It appears that a reasonably satisfactory general model may be possible for some species, which, of course, would greatly simplify the diagnostic system. A wide range of studies of foliar nutrient variations from site to site for various species, analyzed by regression studies, and then followed up by fertilizer test-plot studies will be required before we have effective systems; but the studies to date indicate that such foliar diagnostic systems can work. Other parts of the country, particularly the Southeast (*Pritchett and Smith 1971*), are ahead of us in this, and we could learn a great deal from their methods and results.

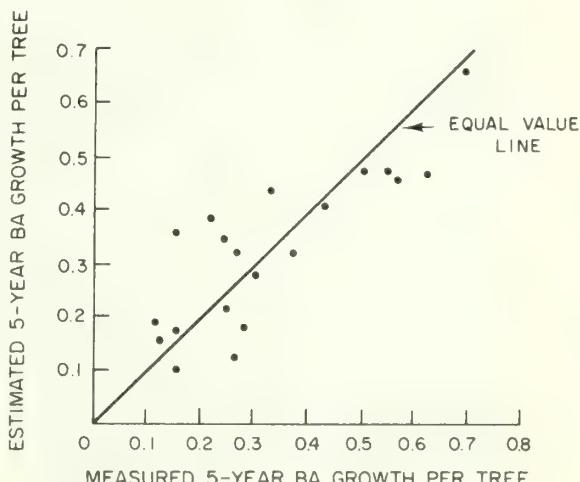
Soil analysis systems for diagnosing nutritional needs and predicting responses have been the primary foundation of fertilization practice in agriculture. They have a number of advantages over foliar-diagnosis systems, most important that they evaluate the nutrient-supplying medium; it is not necessary to have the crop present to predict needs or responses. The results can be interpreted for a wide variety of species and, if necessary,

corrective measures can be applied. Also, the soil is more stable and less affected by other environmental factors.

What are the prospects for soil analysis in forestry? The ideal situation would be a standardized soil-sampling and analysis system, a set of prediction equations for estimating inherent productivity, and an additional set or sets for estimating nutritional status and response. So far soil analyses have not seemed to function as well nor to have been developed to the extent that might have been expected. In many studies in the Northeast and elsewhere we find published foliar criteria for different levels of nutritional status for certain species (*Stone and Leaf 1967; Gessel et al. 1960; Wells and Crutchfield 1969*), but in few cases do we find soil criteria. Although soil tests were run, they were found to be not well correlated with growth or responses to fertilization.

Several factors probably contribute to this lack of success: the soil-testing methods may not be the most suitable ones, as suggested by Voigt (1958) and the work of White and Leaf (1964); the

Figure 8.—Relationship of average measured and predicted basal area per tree growth. Equation $BA = .01710 + .0161 (\% N) - .0177 (\% Ca) - .0371 (\% K) + .2766 (\% Mg)$, $R^2 = 0.68$.



mode of expression of nutrients may not be suitable; or the evaluation of nutrient status may be so intertwined with other site factors that these must be taken into account at the same time, or success is precluded.

Site-index values alone probably will not serve as an effective guide to response (*Heilman 1971*). Although a considerable number of site studies have been carried out in the Northeast to relate soil and other factors to productivity, very few of these have identified significant soil-fertility factors, in spite of the fact that various foliar-diagnosis studies strongly suggest that relationships exist. However, these site studies form a valuable base of information about site productivity and the factors controlling or associated with it, a base that can be used in developing soil-based diagnostic systems for fertilization.

The problems of developing soil-based diagnostic systems seem to be much farther from solution and to require a much greater input of research as compared to foliar systems, but in the long run such systems would probably be preferable. The first problem to be faced is development of soil-testing methods. This will require extensive greenhouse and field tests of fertilizer levels, growth responses, and foliar-nutrient levels to provide a basis of correlating soil-test results with fertility levels and responses on a wide variety of soils, preferably where other environmental factors can be controlled to some extent. After this phase some sort of broad-based field-fertilization and soil-testing experiments will be required to establish response curves for soil groups and fertility levels.

Diagnostic systems combining both foliar and soil analyses are possible, and it is almost inevitable that foliar diagnosis will play a considerable part in the development of soil-testing systems and that foliar analysis is likely to be used as a supplemental or confirming information system. If foliar- or soil-diagnosis sys-

tems are refined sufficiently, each may function without the other; but generally feedback from both is essential to improvement of the accuracy and understanding of the factors controlling nutrient availability and response. However, there is no reason why elements of the two systems could not be combined. For instance, we might find that a foliar-deficiency level of K on a sandy, unbuffered soil might require one level of fertilization, a similar foliar level on a heavy texture soil might require a different level of fertilization, and the diagnosis might be better by using the combination of soil and foliar levels than with either separately. As yet we have little experience on which to judge the possibilities or desirabilities of such systems.

THE URGENT NEED

Perhaps the most urgent need in the Northeast is a wide range of fertilizer test plots for our key sites and species. There is no substitute for field tests to accurately determine responses to fertilization. Successful soil-testing and interpretation in agriculture stem from the wide-spread formal and informal testing of rates, kinds, and methods of application and the rapid feedback of this information through extension specialists and agronomists to the soil scientists, resulting in refinement and improvement of the testing system.

Field tests in forestry, to be of much value, require a considerable amount of planning and effort. Some important considerations include:

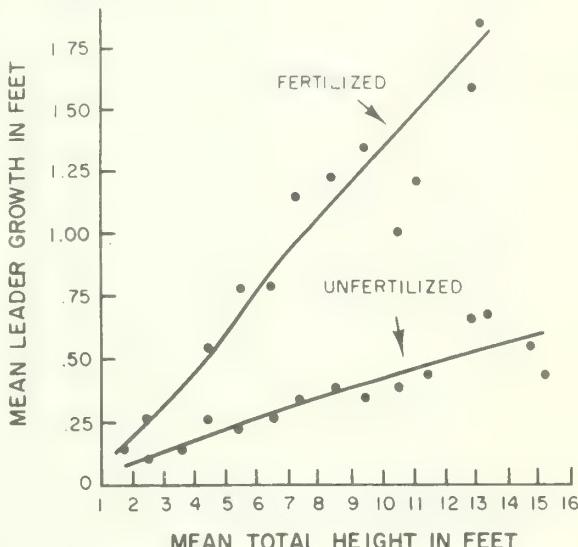
- Important soil-site types and species.
- Site and stand uniformity.
- Plots large enough (1/10 to 1/5 acre) and buffer strips provided so that treatments are effectively isolated.

- A good statistical design for the layout to get maximum benefit. Good control and replication are especially desirable. Several application rates to establish response curves, and combinations of nutrients to establish if simple or complex responses occur. Designs that omit certain nutrients from combinations are supposed to be more efficient than testing of all levels of individual nutrients or combinations. Factorial designs in randomized complete blocks have been suggested by Turnbull et al. (1970) and response surface designs have been suggested by Clutter (1968).
- Accurate evaluation of growth responses.

This last item needs further elucidation. A wide variety of measures have been used by researchers, and the choice of the most suitable one is important. Accuracy and sensitivity of the response measure is of prime importance, but the difficulty and expense involved may also influence choice. Responses can be measured both relative to past growth or in relation to control plots; the latter is preferable because effects of other factors, especially climate, are constant. Height-growth response has been widely used to evaluate fertilization of conifers and is particularly suitable to excurrent tree form. Height poles are good for measuring young trees; Haga altimeters or other types of hypsometers may be accurate enough in some cases; but for tall trees and short periods, transits or other precise optical instruments will be required.

Particularly in younger stands, height growth tends to be related to the size of the tree, so it may be necessary to express this as a percent of previous growth or to segregate height classes to assess response differences. An example of this is shown in figure 9 from Gessel et al. (1960). In older stands, height growth tends to slow down, so total height or age

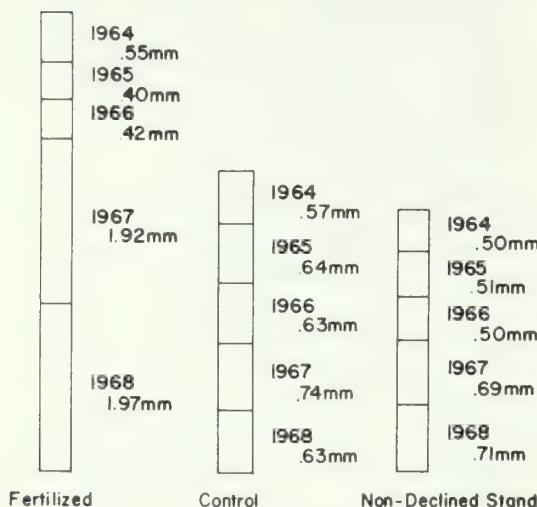
Figure 9.—Effect of fertilization on height growth of Douglas-fir is illustrated by these curves. The upper curve shows leader growth of fertilized 15- to 20-year-old trees of various heights during 1953, and the lower curve compares leader growth of unfertilized check trees in the same height classes. (Gessel, Turnbull, and Tremblay 1960.)



of the stand may need to be considered.

The main problem in using height growth is to translate the response into cubic volume units; for instance, a 50-percent increase in height growth from site index 60 to 90 in white pine at breast-height age 60 results in an increase in cubic volume from 6,800 to 11,000 cubic feet per acre at full stocking—approximately a 62-percent increase. Rates of volume increase relative to height increase differ with age because height growth usually tapers off sooner than gross volume increment (Mader 1968). Conversion estimates can be made by using tree and stand volume tables, but the accuracy is always open to question; so height-growth measurements are good for relative assessment of general magnitude of response, but they leave something to be desired for total volume figures, especially on a short-term basis.

Figure 10.—Mean annual ring width based upon one core from each of six sample sugar maple trees within a plot. (Mader, Thompson, and Wells 1969.)



Measurement of diameter or basal-area growth response also has been used widely and successfully. This is necessary in situations where accurate height measurement is not possible, such as in many hardwood types. The growth responses Mitchell and Chandler (1939) found were based entirely on diameter growth, and diameter growth was effective in assessing growth responses in slow-growing declined maple stands (fig. 10) (Mader *et al.* 1969). Changes in diameter growth can be measured with a diameter tape or calipers, but these devices are of limited accuracy as ordinarily used and would be suitable only if large responses took place. Dendrometer bands are more accurate and are suitable in most cases, but are tedious to make. Dial-gage dendrometers are good for intensive seasonal-response studies, but are too expensive for general use. Measurement of ring growth on increment cores or tree sections is more precise than the other methods for comparing ring width and is one of the best and simplest methods for evaluating diameter growth rates.

In some cases diameter or basal-area growth is compared on a single-tree basis; for instance, Mitchell and Chandler's (1939) data were expressed as an average radial increment in millimeters for dominant and codominant trees in the stand and served as an effective base even though they were dealing with mixed stands and, presumably, a considerable range of tree size where absolute diameter growth values could vary greatly. Extrapolation of such values to other stands of different tree size, age, and density seems very likely to lead to serious errors. Comparisons on a relative basis (Heilman 1971) avoid some of these problems.

Again, we have the problem of converting to cubic-volume equivalent growth increases, which require some height data and use of tree-volume tables. Increases in basal area at different sizes, ages, and densities may not be equal on a percentage basis nor have a constant relationship to volume increases, complicating such projections; however, they may be somewhat better and more consistent than height-volume change relationships. Basal-area response is most logically applied on an area basis rather than on a single-tree basis. If data are taken carefully on the whole plot or a good sub-sample so that basal-area increase comparisons can be made on an area basis, variations in stand density and tree size are less important; and either relative or absolute comparisons are more precise and more safely extrapolated to other stands. Conversion to volume-response estimates can probably be reasonably good with some height data and use of the equations from yield-table studies to compute volumes. These are generally based on basal area, height, and form-class functions.

The current ultimate measure of response in respect to fiber production is actual cubic-volume increase in the stems. If both height and diameter increases are measured carefully, plus form

class, quite accurate volume increase for each stem can be calculated from standard tables, and both absolute and relative volume increase of the stand can be determined. Even more precise estimates can be obtained by stem analysis from increment cores or sectioning, and calculating volume increases by sections of the stem for each tree or selected representative sample trees. This latter process is a tedious one and feasible only on small and intensively studied areas.

To get good volume-increase data at a reasonable cost, breast-height increment-core analysis for several sample trees from each diameter class is probably sufficient. Those data can be used to project diameter increase for all the trees in the stand. Sample-tree height measurements can be used to construct a height-diameter curve, and form class can be determined for different diameter classes. Form-class tree-volume tables or equations can then be used to compute stand volume per plot and the change in volume. The other alternative is to take one or two trees from each diameter class and do a total stem analysis on them, projecting volume and volume change for the remainder of the stand from curves or equations based on the sample trees. In any case good volume response data per acre are not easy to obtain.

The problem of length of response period to fertilization is another important aspect of plot fertilizer trials. This must also be obtained from good experimental plots established for long periods of time. Responses from nutrients that cycle rapidly may be long-lived, as reported for K with red pine by Heiberg et al. (1964). Or they may be more short-lived for those that are tied up in large amounts in plant tissues and cycle slowly, as reported for N by Heilman (1971). Growth response often does not occur until the second growing season after treatment, may peak for a few years, and then gradually decline.

To summarize the current situation in

terms of assessing fertilizer needs for managing foresters in the Northeast, we have very limited tools. Foliar diagnosis can be used to identify some severe deficiencies where good response to fertilization is highly probable; where severe deficiencies do not exist, foliar diagnosis is not very helpful, and we cannot predict either the direction or magnitude of response to fertilizers. Soil analysis or just identification and classification is presently even less helpful than foliar analysis. It will help us identify very infertile sites but will not tell us the need for fertilization or the response to expect.

The most immediate prospects for successful diagnostic systems seem to be with foliar analysis. They probably can be developed faster, easier, and more cheaply than soil-based systems where testing methods present a formidable development task. I think these foliar systems can be developed successfully in the near future with moderate research inputs and cooperative effort in the region.

Perhaps the most urgent need is for a cooperative effort to install well-designed fertilizer test-plot studies over a wide range of sites for several of our key species. This type of program is under way in the Southeast, such as the CRIFF (Cooperative Research in Forest Fertilization) program in Florida (*Pritchett and Smith 1971*). Such fertilizer test-plot programs are essential as a basis for either foliar- or soil-diagnosis systems to obtain data for development of response curves, to segregate different kinds of sites if necessary, and to provide feedback for improvement and development of prototype systems.

As for the future, what is really going to happen? If the companies and agencies interested in wood-fiber production are willing to support and cooperate in the research, the research necessary to put forest fertilization on a sound basis in the Northeast can and will happen over the next 10 to 20 years. I am not

fully convinced that companies feel their fiber needs are critical enough now or will be in the near future to make them want to support the research.

In spite of preliminary favorable results from other regions, the economics of fertilization in the Northeast for the future is an open question, and industry is not prone to gamble too much on open questions. However, it is fairly obvious that the universities and federal agencies in forestry research are in a period where problems other than wood-fiber production in the Northeast get highest priority, and the allocation of funds and effort from these sources toward solving the problems is apt to be less, rather than more. Research related to fertilization is apt to be directed more toward health and vigor problems rather than wood-fiber production. Naturally, such studies will produce information about nutrient demands and productivity, but that will not be the main objective, and progress will be slower.

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SOIL AND PLANT ANALYSIS TECHNIQUES AS DIAGNOSTIC CRITERIA FOR EVALUATING FERTILIZER NEEDS AND TREATMENT RESPONSE

by K. A. ARMSON, *Professor of Forestry, University of Toronto, Toronto, Ontario.*

ABSTRACT. Use of soil and plant analysis techniques must take into account both stage of development and rate of growth of the tree crop, and the environmental conditions under which the crop exists. The principles and relationships between plant growth, plant nutrients, and soil nutrients are illustrated. Soil and plant analyses have been used both comparatively and mathematically. The precautions necessary in sampling and use of chemical procedures applied to plots and soils are discussed briefly.

HERE IS a voluminous literature dealing with the soil and plant analysis techniques used to evaluate the nutritional status of plants. Here I will place the major emphasis on the principles employed and their application to forest trees, especially those of eastern North America.

Much of the background for studies of forest soils and trees has, as might be expected, come from earlier work in agriculture, and this is especially true for the analytical techniques. Within the past few decades, however, there has been developing within forestry an expertise specifically related to the diagnostic use of soil and plant analyses. That this proficiency has not been developed more is a reflection of the general low level of intensity of forestry practices, particularly those of silviculture.

The use of soil and plant analytical techniques for diagnostic purposes must be viewed in the context of the crop and the environmental conditions under which it exists. A diagnosis involves the interpretation of quantitative information about soils and plants. If the diagnosis is to be meaningful, it must take into account both the stage of development and the rate of growth of the crop either for an individual tree or on a per unit area basis. Too often there is a tendency to consider the application of an analytical technique in isolation. There are, I believe, two main reasons for this: one is the human urge to simplify, to search for a single index or yardstick; the other is the specialization associated with the elaborate and sophisticated techniques that develops in any area of knowledge.

BASIC RELATIONSHIPS

Analyses of soils or plants usually are considered in relation to the size or growth of the plant, and there have been developed certain principles and relationships between two or more of these parameters (soil nutrients, plant nutrients, and plant size or growth) that are useful for diagnostic purposes. Figure 1 illustrates certain simple relationships; thus when a nutrient limits growth, an increase in supply of nutrient is associated with increase in plant absorption and a concomitant increase in plant size. The growth-response curve is curvilinear, as is the increase in nutrient concentration with increase in supply; but when the concentration of nutrient in the plant increases beyond the level of supply at which there is any plant growth increase, then there is said to be *luxury consumption* of the nutrient.

In some instances the nutrient present

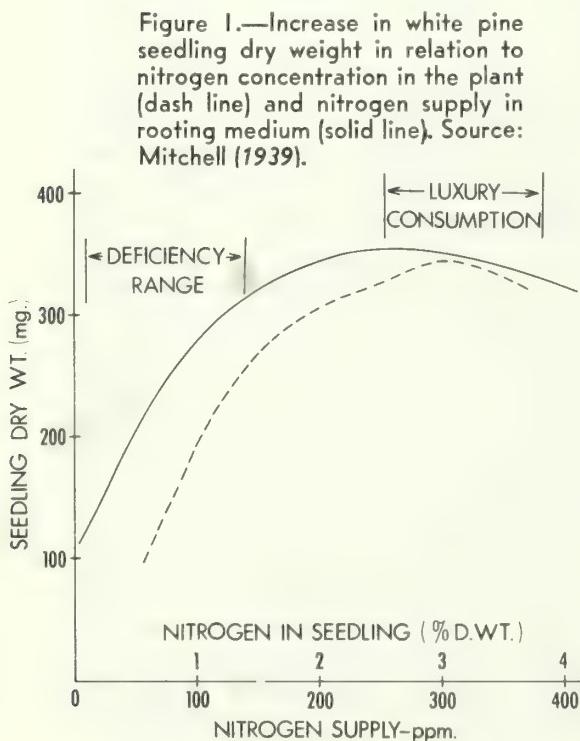
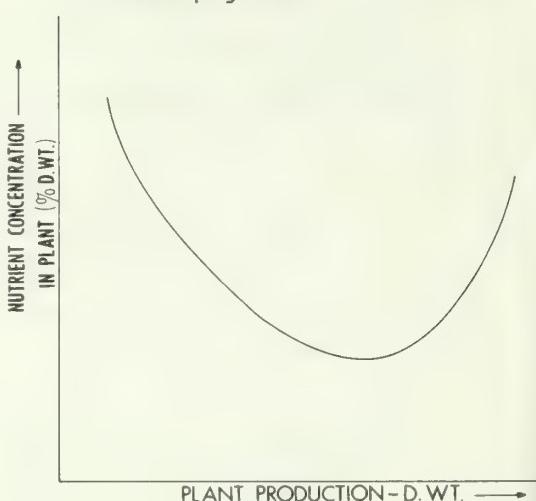


Figure 1.—Increase in white pine seedling dry weight in relation to nitrogen concentration in the plant (dash line) and nitrogen supply in rooting medium (solid line). Source: Mitchell (1939).

Figure 2.—Relation between nutrient concentration in plant and plant production to illustrate Steenbjerg Effect.

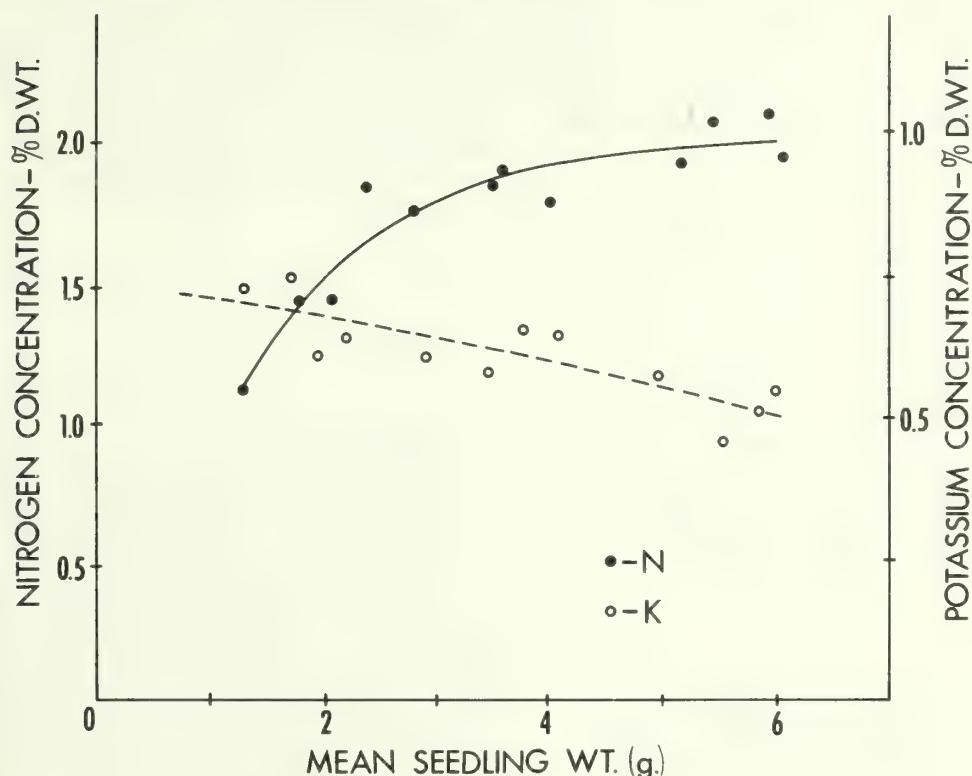


in limiting amount in the plant may show first a decrease and then an increase in percentage concentration with increase in plant size (fig. 2.). This, termed a *Steenbjerg effect*, is associated usually with certain micronutrients such as copper (Steenbjerg 1954). Such an effect can sometimes be observed over a short period of time when there is a large growth response to addition of a major nutrient.

Frequently, when plant analyses are employed, the level of more than one nutrient element is determined. An increase in the supply of a limiting nutrient that results in increased growth may result in a decrease in the concentration of other non-limiting elements (fig. 3). This is termed a *dilution effect*. As the dilution progresses, the level of the nutrient may become low enough that it in turn limits growth, and a stage is reached at which the increase in supply of one nutrient may induce a deficiency of another element.

Generally, when plant analyses are undertaken for diagnostic purposes, only a

Figure 3.—Relationships between foliar nitrogen and potassium concentrations and associated mean seedling dry weights. 2 + 0 white spruce. Source: Armson (1968).



portion of the plant is sampled, and the level of the nutrient is expressed as a concentration (dry-weight basis). This value usually does not reflect the content or uptake, which refers to the absolute amount of the element within the plant or plant organ. It is unfortunate that in much of the literature the terms *concentration*, *content*, and *uptake* have been used synonymously.

Plant and soil analytical data have been used either diagnostically or as guides to adequate levels in soils and/or plants in two main ways, comparative and mathematical.

Comparative Analyses

Samples from trees or stands that are considered to exhibit satisfactory growth and corresponding samples from the soils

in which the trees are growing may be analysed, and the levels of nutrients in these samples have been used as standards to compare other stands of trees and soils. At best, comparative analyses serve to provide ranges of values, and where the comparisons are between individuals of the same species, of the same age, and growing in the same location on the same soil materials, the data may be of value (Madgwick 1964), especially where nutritional differences may be related to some aspect of soil use (Armson 1959; Heiberg and Loewenstein 1958). The greatest unreliability of comparative values may be expected when values are extrapolated from one growing location to another or from a tree or stand at one stage of development to another of a different age class or stage of development.

Mathematical Relationships

The curvilinear relationships that are often found to exist (fig. 1) between plant growth, nutrient content or concentration in the plant, and nutrient supply from the soil, have been used to detect nutrient deficiencies and also to predict possible growth response. Often, for simplification—and based on the reasoning that over the most deficient part of the curve it approximates a straight line—linear regressions have been widely used.

Plant growth—plant nutrient relation.

—An example of a simple relationship is shown in figure 4. The seedlings were growing in a nursery seedbed under uniform conditions, and the highly significant linear correlation between growth and N concentration indicates that the supply of N was limiting and variable. A more sophisticated multiple regression

was developed by Leyton and Arsmson (1955) and used to determine, tentatively, that N and K were most likely limiting the height and dry-weight growth of the Scots pine (*Pinus sylvestris* L.) trees studied. Later, Leyton (1956), used the same technique on a plantation of Japanese larch (*Larix leptolepis*, Murr.) and determined the following regression:

$$Y/(\text{Ht.} - \text{cm}) = 123.3 \text{ N\%} \\ + 188.7 \text{ K\%} - 180.9$$

S.E. of estimate = ± 41 cm.

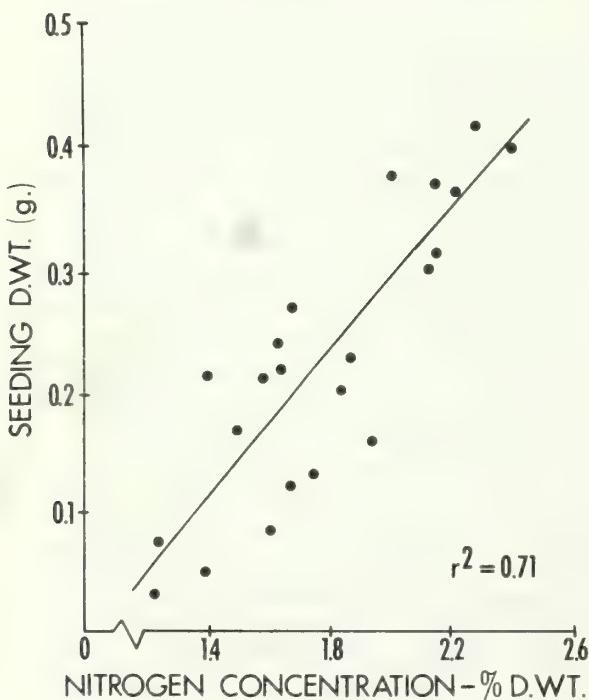
and $R = 0.916$.

Subsequently (Leyton 1957) a fertilizer trial using N and K was set out in a similar-aged plantation of the same species a short distance from the one previously studied; and growth responses, primarily to N and to a much lesser degree K, were obtained. Although the quantitative relationship between tree height and foliar concentrations of N and K were substantially different than formerly, the general value of the technique was demonstrated.

Hoyle and Mader (1964) undertook a comprehensive study of the relationships of foliar nutrients to growth of red pine (*Pinus resinosa* Ait.) and found that in nearly all instances higher correlation coefficients were achieved by using total foliar nutrient contents rather than percent concentrations. The choice of growth parameters was important because foliar Ca was related to height, foliar K to basal area, and soil moisture to volume.

The interpretation of such mathematical relationships must take into account the fact that the growth parameter chosen may be important, as Hoyle and Mader (1964) demonstrated. In addition, other factors both external and internal to the plant may affect the relationship. Supply of soil moisture may vary from one growing season to the next and so alter growth-nutrient relationships. An increase in uptake of a limiting

Figure 4.—Relationship between mean seedling dry weights of 2 + 0 red pine seedlings and seedling foliar nitrogen concentrations.



nutrient will often change the balance of other nutrient elements. For example, Leyton (1957) found that N/P and N/K ratios were related to growth and suggested that the ratios might have a value for diagnostic purposes.

Another procedure to establish plant growth-soil nutrient relations involves sampling a species population and attempting to correlate some measure of growth with one or more plant nutrient levels, as for example in a study by Stone *et al.* (1958).

Plant growth—soil nutrient relations. Attempts to relate plant growth to soil-nutrient analyses have been generally less productive in terms of diagnostic use than those employing plant-growth/plant-nutrient values. There are two prime reasons for this. One is the difficulty in determining meaningful values for availability of a particular nutrient to a plant; thus any method of extracting an element from the soil is arbitrary and its applicability to a particular tree must be previously established. Many, if not all, chemical extractions will give different values, depending on the soil properties.

The second reason is the variability in the distribution of tree roots. For tree nurseries where the plow layer is relatively homogeneous and is also the prime zone for rooting, the use of soil analyses is most useful. In forest soils where there is not only considerable variety between the major horizons (O, A, B, C), but also often within horizons of a profile, and also major differences in rooting intensity within the soil profile, adequate sampling techniques have yet to be established. Leaf and Madgwick (1960) have also stressed that results of soil analyses for forest soils must be expressed on a soil volume basis, and for this to be done, bulk density and stoniness must be measured.

In eastern North America, the major attempts to relate soil nutrient levels to plant growth have been in the Northeast,

where soil K and red pine growth have received attention, and the Southeast, where soil P has been studied. For red pine, White and Leaf (1964, 1965) found that none of the extraction values for potassium were significantly related to tree height when *only the solum was sampled*, but that nitric acid extractable K, from materials towards the bottom of the solum and just below it, was highly correlated with total tree height. Pritchett and Llewellyn (1966) studied the response of slash pine (*Pinus elliottii* Engelm. var. *elliottii*) to phosphate additions in sandy soil and, although there was a growth response to fertilizer addition, total soil P values were not correlated with increase in growth and ammonium acetate extractable P values were negatively correlated with tree height growth the third year following treatment.

Certain studies have involved the sampling of a species over a geographic range and making graphical or mathematical comparisons of the variation in growth with various soil properties. Wilde *et al.* (1964) and De Ment and Stone (1968) have used this technique for red pine plantations. Such studies have value in the management of a species in the area in which they are conducted, but must be used with caution when applied to other areas.

Plant nutrient—soil nutrient relations. —In certain instances, relationships between plant nutrient and soil nutrient levels have been established. Walker (1955), for example, demonstrated that strong correlations existed between exchangeable K levels in the soil and K concentrations in the foliage of white pine (*Pinus strobus* L.), choke cherry (*Prunus virginiana* L.) and certain herbaceous species in New York. One of the objectives in determining such correlations, particularly for native vegetation, is to develop a useful diagnostic technique for selecting tree species for planting.

Thus, if white pine is known to be susceptible to K deficiency, and it can be established that some commonly occurring native plant exhibits a relationship between soil K supply and plant K supply over the range of deficiency to nondeficiency in white pine, then sampling of the native plant will provide prior information useful in making a planting decision for the pine. Obviously, this application suffers from the limitations related to soil heterogeneity, rooting distributions, and plant-sampling variation. Often no clear-cut relationships exist; Gagnon *et al.* (1958) found no relation between the levels of nutrients in a number of species of lesser vegetation and nutrient content of the humus, although the levels in the humus (H) horizons did show a consistent increase with site class.

Our information and understanding of soil-plant nutrient relations is ultimately based on experimental studies in which one or more species are subjected to fertilizer additions on different soils. Usually, only stands of uniform density are considered, yet in natural stands where the information is most likely to be applied, stand density is often quite variable. Further, even in stands such as plantations, which may be initially of uniform density, there is inevitably a change in density as the trees develop. Surprisingly then, diagnostic studies in which variations in stand density are employed are uncommon.

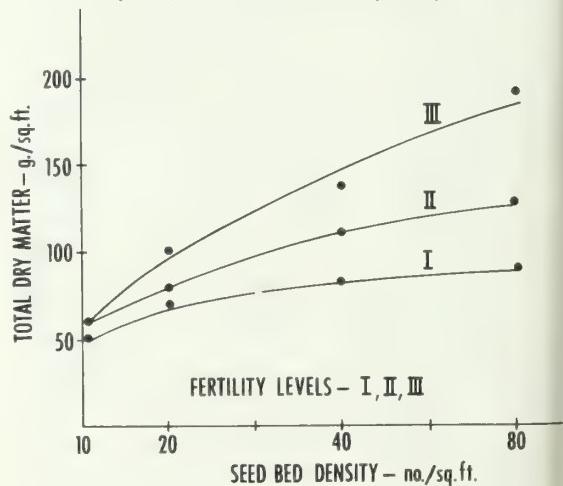
In a study of white spruce (*Picea glauca* (Moench) Voss.) and red pine, Armson (1968) showed that seedling density would profoundly affect both individual seedling size and foliar N concentration (table 1). Total dry-matter production per unit area also will reflect nutrient supply and stand density (fig. 5), and thus any interpretation of plant growth and plant N concentration, or a decision to alter production on an area basis by changing nutrient supply levels must take such density factors into consideration.

Table 1.—Mean seedling dry weights and foliar N concentration for 2-year white spruce seedlings grown at four densities (10, 20, 40, and 80 per square foot) and three levels of soil fertility (increasing I → III)

Fertility level	Seedling density—No./sq. ft.							
	10		20		40		80	
	Dry wt. g.	N pct.	Dry wt. g.	N pct.	Dry wt. g.	N pct.	Dry wt. g.	N pct.
I	5.2	1.8	3.6	1.9	2.1	1.4	1.3	1.1
II	6.1	1.8	4.0	1.7	2.8	1.7	1.8	1.4
III	6.0	2.0	5.5	1.9	3.5	1.8	2.4	1.8

Source: Armson (1968).

Figure 5.—Total dry-matter production in relation to seedbed density and increasing soil-fertility levels—I, II and III 2 + 0 white spruce. Source: Armson (1968).



Heiberg *et al.* (1959) presented data on the response of red pine plantations to various levels of K fertilizer additions. Height growth of pine at a spacing of 6 x 6 feet, and addition of 50 lb./acre of K fertilizer was slightly greater than that achieved by pine at 4 x 4 spacing and a fertilizer addition of 150 lb./acre. Although individual tree size was greater at the lower density, on a per-acre basis volume growth increased curvilinearly with increase in K supply.

DIAGNOSTIC OBJECTIVES

There are three major objectives, one or more of which may be considered when soil and plant analysis techniques are employed diagnostically. To some degree the analytical techniques may vary with the objective.

(1) *To determine why a tree or stand exhibits poor growth and/or foliage or other organ abnormalities such as discoloration or unusual development*

Most frequently the symptom observed is foliage discoloration, and studies such as those of Swan (1960, 1966, and 1970) for conifer seedlings and Haskaylo *et al.* (1969) for deciduous species provide not only pictorial records of visual symptoms but also associated foliar concentrations for several nutrient elements. Sometimes the identification of the nutrient element involved in the abnormal condition is only part of the diagnosis.

For example, in conifers the uptake of N may be highly correlated with increase in growth, and any factor that will reduce the ability of the tree to absorb N will also reduce growth and result in symptoms of deficiency. One of the symptoms of littleleaf disease (*Phytophthora cinnamomi* Rands.) is chlorosis and reduced N concentrations in the foliage of shortleaf (*Pinus echinata* Mill.) and loblolly (*Pinus taeda* L.) pines, yet the cause is the reduction in absorbing roots due to their mortality caused by the disease organism (Campbell 1954).

The stage of development of the tree may be important for diagnostic purposes. K deficiency symptoms in red pine, in outwash sandy old-field soils, occur 5 to 6 years after planting (Heiberg and White 1950); and typically the foliar discolorations appear in the 1- and 2-year-old foliage in June at the time of main height growth and current-year-needle development. Purpling in new needle tissue in white spruce seedlings,

which is a symptom of P deficiency, develops typically about 35 days after germination or in mid-summer when, although overall growth rate may be high, root elongation is normally at a minimum.

(2) *To determine the occurrence of nutrient deficiencies that inhibit growth in a tree or stand.*

These conditions would primarily be in trees for which growth might be restricted by one or more deficiencies, but visual symptoms or abnormal growth would not be apparent. It is in such situations that plant analysis, particularly of foliage, has been most widely used. Frequently the concept of critical concentration has been employed. Critical concentration has been defined as "that concentration of a given form of a specific nutrient within a specific plant part at which plant growth begins to decline" (Ulrich and Hills 1967).

Although the diagnostic use of nutrient concentration has found certain uses in agriculture, it must be emphasized that if more than one nutrient limits growth, the estimation of a critical concentration for each one is usually invalidated. Use of plant concentrations can only be applied when the variation in nutrient levels is well known, as for example in black spruce (*Picea mariana* Mill. B.S.P.) and jack pine (*Pinus banksiana* Lamb.) (Lowry and Avard 1965, 1968a, 1968b), loblolly pine (Wells and Metz 1963), and white and red pine (White 1954).

Multiple-regression techniques (Leyton and Armonson 1965; Leyton 1956, 1957; Hoyle and Mader 1964); such as have already been described, would appear to have considerable application in the detection of nutrient deficiencies. Factors other than soil fertility may have to be taken into account when plant-analysis techniques are used diagnostically. The moisture-supplying ability of a soil is one of the most common factors to

affect tree growth and interact with nutrient levels. Jurgensen and Leaf (1965) described a red pine stand in which the depth to water table varied from 0.61 m. to 4.9 m. Growth in terms of height and dry weight increased with increase in depth to the water table. At 26 years of age, the stand was fertilized with K and some 10 years later plant analysis indicated that the foliar K concentrations were related to depth to water table—decreasing concentration associated with decreased depth to water table—but the relationship held only in the oldest (4- and 5-year-old) needles.

The use of plant-tissue analysis in relation to a stand growth parameter such as site index is exemplified by the relationship between foliar K (1-year-old needles) and site index for red pine (Stone *et al.* 1958). Soil analyses have generally been of less utility in prognosis. One of the few areas where soil techniques may be used is in tree nurseries where, on an empirical basis, levels of such elements as P and K may be established for a particular crop.

The principal difficulties in using plant, and particularly soil, analyses for the determination of nutrient deficiencies are those related to sampling procedures.

(3) *To control and regulate the nutrient supply to a tree or crop in order to produce a crop to meet specific objectives of management.*

The specific objectives may be various, ranging from the production of a large vigorous crown for aesthetic purposes, seed production, specific diameter increment for sawlog or veneer utilization, maple sap yield, to maximum cellulose production per acre. For these purposes, plant and soil analytical techniques may be used primarily to monitor the nutrient status rather than detect deficiencies. Nutrient additions may be made in relation not only to growth of the trees but to their stage of development. In such instances the physiological development of

the tree or stand becomes an item of major importance. Thus, in order to induce increased female conelet production in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), both the form of N and the time of application are critical (Ebell 1962).

An example of patterns of stand growth and development that may have relevance is provided for loblolly pine by Switzer *et al.* (1968). Figure 6 illustrates the trend in production of bolewood dry matter and foliage. Note that the current annual increment of the foliage is at a maximum at about 25 years, whereas stem increment peaks at 30 years. However, the stand foliage N content is at maximum at about 15 years. Thus the procession of maximum foliage N content in the stand crown, followed by foliage dry weight and then stem weight, suggests that the photosynthetic activity of the stand may be capable of some manipulation by regulating the N inputs. N additions would have greatest effect if made at the time of inflection of the curve of N foliage content at stand age of 8 years; this should enhance bolewood increment in the following decade or two. The delayed response of trees to changes in soil fertility has already been demonstrated in red pine by Heiberg *et al.* (1964).

In any sophisticated, responsible form of forest management in which considerations of soil fertility and its manipulation are considered, the context in which treatments may be applied takes on importance. Although the objective may be to produce more fibre per acre or more maple sap yield, the stands themselves interact with their environment so that the possible effect of nutrient additions to produce the desired objective not only in the crop but also in other vegetation, and the processes involved in cycling nutrients in the system, should be examined and assessed.

Any application of plant and soil analysis techniques must therefore be extended to other components of the sys-

Figure 6.—Left: current annual increment for stems and foliage of loblolly pine. Right: accumulation of nitrogen in stems and foliage of loblolly pine. Source: Switzer et al. (1968).

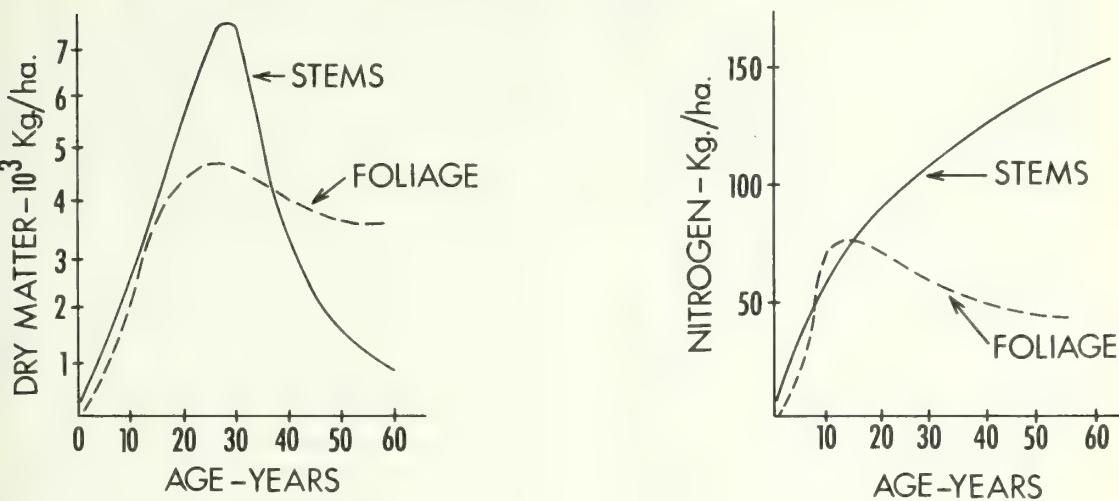
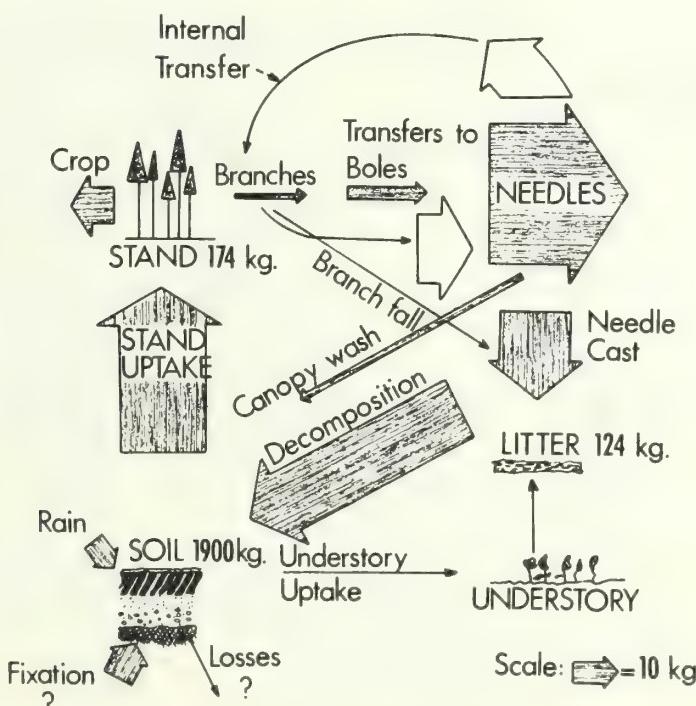


Figure 7.—Annual circulation of nitrogen in a 20-year-old old-field loblolly pine plantation. Thickness of arrow indicates magnitude of flow. Source: Switzer et al. (1968).



tem. As an example of such an approach, figures 7 and 8 illustrate the circulation of N and K in two conifer stands. In loblolly pine (fig. 7) the major portion of the N is cycling in the stand and its components, and an insignificant portion enters into the understory or lesser vegetation. In the Scots pine, however, the circulation of K is mainly in the lesser vegetation (ground flora); hence inputs of these nutrients to their respective stands will follow different paths.

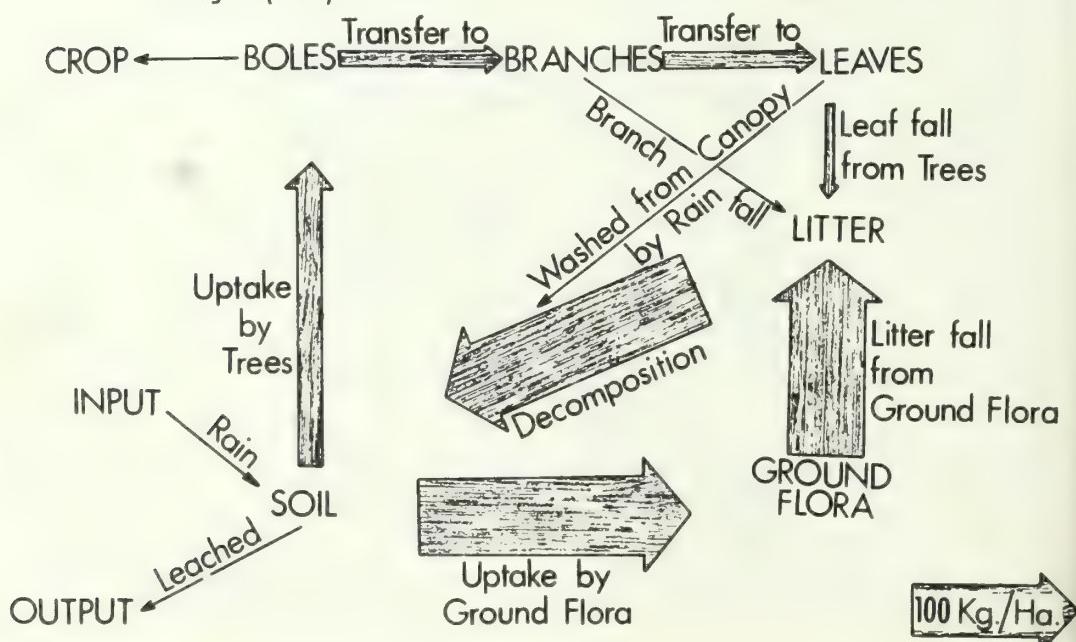
These examples also provide evidence of the importance that other silvicultural practices might have that could affect the use of analytical techniques, and particularly the interpretation of such data. For example, in figure 8 any treatment to remove the lesser vegetation would block the major cycling of K in the system.

Finally, it must be stressed that the use of soil and plant analytical techniques can produce data of significance for diagnostic use only when the variables are known that affect the data, such

as sampling and its associated variables, and the choice of sample treatment, extraction, and chemical procedures employed. The use of plant analysis in forests has been very thoroughly reviewed by Leaf (1972). The serious problems in sampling forest soils that exhibit a high degree of variability have been discussed by Mader (1963), and McFee and Stone (1965) have presented data on variation in nutrient contents in a forest podzol. Metz *et al.* (1963) provided information not only on soils but also on sampling foliage in loblolly pine and recommended numbers of plots and numbers of trees for sampling both foliage and soil.

One of the greatest handicaps in the use of soil analyses is the fact that any method of extraction of a nutrient from the soil must necessarily be arbitrary, and whether it approximates the availability to a particular crop tree can be fully established only by rather time-consuming studies. Voigt (1966) has shown that P taken up by pitch pine (*Pinus rig-*

Figure 8.—Circulation of potassium in a 47-year-old Scots pine plantation. Thickness of arrow indicates magnitude of flow. Source: Ovington (1965).



ida Mill) was related to water-soluble P, and P extracted by 0.002N H₂SO₄, HOAc-NaOAc, and NH₄F-HCl in the rooting zone of the soil. Only the last three extractions yielded values of P that approximated the tree's annual uptake.

The employment of soil and plant analytical techniques for diagnostic purposes will undoubtedly increase as forest-management practices develop and become refined. The use of such techniques not only involves greater skill and knowledge associated with the analytical procedures themselves, but presents a challenge to professional forestry because the intelligent use of these techniques will demand a more complete knowledge and understanding not only of the trees and forest stands themselves but also of the ecological systems of which they are a part.

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EFFECTS OF FOREST FERTILIZATION ON WOOD QUALITY

by WILLIAM T. GLADSTONE and RICHARD L. GRAY,
respectively Forest Geneticist, Southern Forestry Research
Center, Weyerhaeuser Company, Hot Springs, Ark.; and Teach-
ing and Research Assistant, Department of Wood Products
Engineering, State University of New York College of Environ-
mental Science and Forestry, Syracuse, N. Y.

ABSTRACT. Recent studies demonstrate an increase in the uniformity of wood as a result of fertilization. An increase in cell-wall thickness of earlywood fibers and a simultaneous thinning of latewood fiber walls were induced in fertilized red pine and Douglas-fir. Wood quality, for the pulp and paper industry, is generally enhanced by such uniformity. Strength properties of pulps produced from fertilized trees are as good as or better than those of pulps from unfertilized trees.

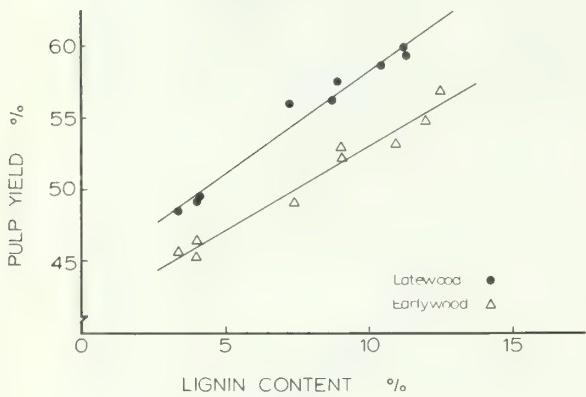
IN A REVIEW of the effects of fertilization on wood quality, Klem (1968) concluded that the results of forest-fertilization treatments depend to a great extent upon the condition of the trees before treatment. When differences in species, treatments, and other factors are superimposed on preconditioning, it is not surprising that a spectrum of responses is observed and that apparent inconsistencies are recorded.

It is not our intent to review this response spectrum nor to report on a specific investigation, but we do propose to tie together some recent research results that promise to assist in justifying certain forest fertilization efforts.

QUALITY RELATIONSHIPS: WOOD-PAPER

Wood specific gravity and the generally correlative parameter of mean cell-wall thickness are measures of wood quality that provide excellent predictions of the general suitability of wood as a raw material for papermaking. Obviously wood specific gravity (or wood density) and the yield of pulp per unit *volume of dry wood* are related. More digester capacity is required to produce a given daily tonnage of chemical pulp from wood of low specific gravity than from denser wood. Operating efficiencies are generally higher with wood of high specific gravity.

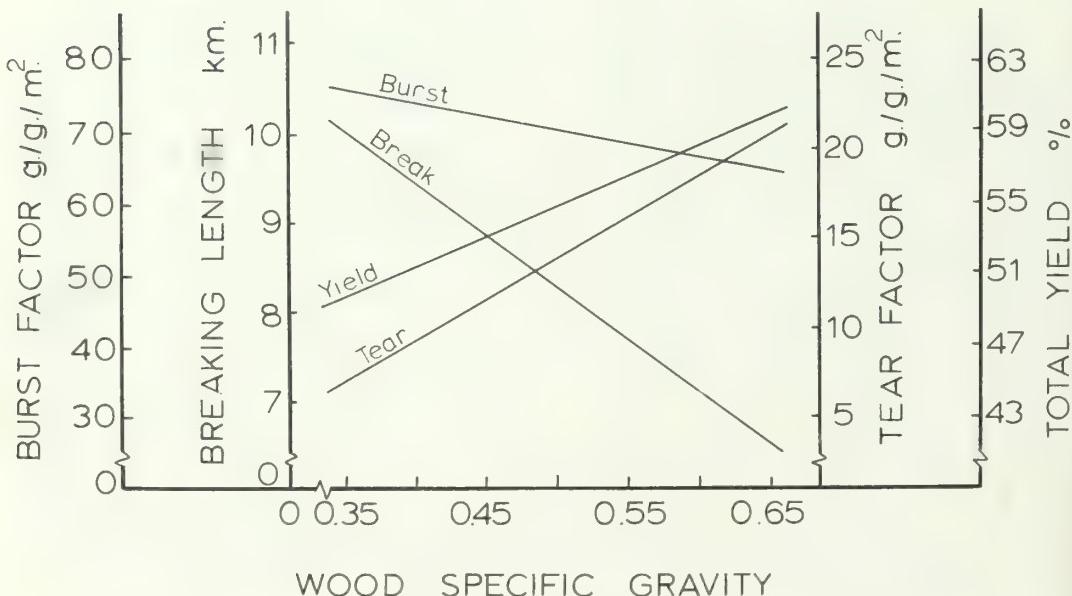
Figure 1.—Regressions of kraft pulp yields from earlywood and latewood (from a single loblolly pine) on lignin contents of the respective pulps. A range of pulp lignin contents was obtained by varying cooking time. Yields are expressed on an extracted wood weight basis. From Gladstone *et al.* (1970).



Somewhat more subtle is the emerging positive relationship between specific gravity and chemical pulp yield when yield is calculated on a *dry wood weight basis*. This relationship is particularly evident within a given tree and is probably applicable to those coniferous species that produce distinctive latewood.

A higher kraft pulp yield from loblolly pine latewood, relative to that from earlywood, was recorded by Gladstone *et al.* (1970) (fig. 1). Percent of latewood seemed to be the morphological feature that best established the total kraft pulp yield to be expected from a given lot of loblolly pine wood (Barefoot *et al.* 1969). A positive relationship between specific gravity and total yield established in that study (fig. 2) confirmed a well-established positive correlation between percent latewood and specific gravity. The demonstrated superiority of mature pine wood over juvenile wood (juvenile wood has less latewood) with respect to

Figure 2.—The effect of wood specific gravity on the properties of moderately refined kraft pulps prepared from loblolly pine wood. Yield is calculated on a wood weight basis. Adapted from Barefoot *et al.* (1972).



weight-based pulp yield supports these observations.

Regressions show the effects of loblolly wood specific gravity on three important strength properties of kraft pulp (fig. 2). Though these are exactly appropriate only for the material from which they were derived, they are indicative of the general relationships for coniferous wood and associated chemical pulps. Note that the measure of resistance to tearing, like yield, is positively related to specific gravity. However, bursting strength and breaking length (a measure of tensile strength) are related inversely to specific gravity, and the technologist is faced with expensive choices if either or both of these latter properties are essential to specific paper products.

In general, wood composed of fibers having the thick cell walls typical of latewood tends to produce high weight-based yields of pulps, while these same thick-walled fibers provide excellent resistance to tearing. However, their tendency to retain their tubular form and thus to minimize surface contact between fibers in a paper web results in lower burst and breaking-length properties than can be achieved with the thin-walled collapsible fibers characteristic of earlywood. Tearing resistance, of course, is lower in the earlywood, as is weight-based yield.

QUALITY RELATIONSHIPS: FERTILIZED-UNFERTILIZED WOOD

An increase in the rate of wood volume production is a desirable and frequent result of forest fertilization. Equally frequent, and often less desirable to fiber-using industries, are changes in the anatomy and anatomy-dependent physical characteristics of wood formed under various treatment regimes.

For example, fertilization often results in a decrease in wood specific gravity due to an increase in the proportions of thin-walled earlywood fibers in a given annual

increment and to a concurrent decrease in the thickness of latewood fiber walls.

Such changes in wood quality will result in:

- A substantial loss in pulp yield per unit volume of wood—unfavorable.
- A moderate loss in pulp yield per unit weight of wood—unfavorable.
- A loss in tearing strength accompanied by increases in breaking length and bursting strength—desirable for some products, but not for others.

The net effect of these changes in wood quality must be offset by the value of additional wood volume beyond what is necessary to justify the cost of fertilization.

Other responses have been observed. Fertilization can also produce woods of specific gravities, proportions of latewood, and/or fiber wall thicknesses that are equal to or higher than those of associated unfertilized wood. In any instance, if pulp yields, both volume- and weight-based, and pulp properties, are *not* affected adversely by the treatments, then growth (volume) increases due to fertilization may be accepted at face value.

Several instances where fertilization has resulted in increased wood uniformity or in somewhat favorable pulping characteristics have been described recently. The parallel trends observed in Douglas-fir (*Megraw and Nearn 1972; Siddiqui et al. 1972*) and red pine (*Siddiqui 1970; Gray 1970*) should be of particular interest to persons involved with commercial forest fertilizer application.

WOOD UNIFORMITY: RED PINE

The red pine (*Pinus resinosa* Ait.) example involves wood formed after relatively slow-growing trees here at the Pack Demonstration Forest were treated with K at the rate of 200 pounds per

acre. This treatment, though it resulted in substantial growth increases, was in fact remedial and was designed to overcome an extreme K deficiency. Our interest thus lies primarily in comparing the wood quality responses due to the K treatment with those resulting from the N fertilization of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco.] growing on a quality-3 site.

An examination of some gross wood properties in the course of a pulping study of the fertilized and unfertilized red pine indicated that, though the proportion of latewood was slightly lower in the wood from fertilized trees, there was essentially no difference in specific gravity between these two wood types (Siddiqui 1970). Kraft pulp yields, calculated on a weight basis, also remained constant, the mean yield values being 47.8 and 47.7 percent respectively for fertilized and unfertilized wood.

Since specific gravity and yield per unit weight of wood were unaffected by the increased diameter growth produced by fertilization, no effect on pulp yield, weight or volume basis, was observed. An examination of the papermaking properties of the fertilized and unfertilized pulps, however, indicated that the treatment did alter the characteristics of the wood fibers (table 1).

For clarification: the term *unrefined pulp* describes a mass of fibers essentially as they are when released from the original wood through chemical digestion. *Refining* implies a mechanical treatment of

the fiber mass designed to collapse and fibrillate or fray the individual fibers and thus to increase their interfiber bonding potential when formed into a paper sheet.

The interaction of fertilizer treatment and pulp-refining produced results that seem anomalous. Considering that the percentage of latewood decreased somewhat with fertilization, we anticipated that burst factor and breaking length would be higher in fertilized wood than in unfertilized wood, and that the reverse would be true for tearing strength. With refined pulps, breaking length fulfilled this expectation while burst factor and tear were unaffected by fertilization (table 1). The net effect of rapid growth on refined pulp quality was favorable in that breaking length improved while tearing strength did not decrease.

Practically, the properties of unrefined pulps are of lesser significance, however in this instance they do provide insight to related wood and fiber characteristics. Strength properties of the unrefined pulps were not consistent with a decrease in the proportion of thick-walled latewood fibers. Burst factor and breaking length both decreased with fertilization while tearing strength increased, changes that would be expected to accompany an increase in latewood percentage rather than a decrease.

The data suggested that, though the fertilized wood contained more earlywood than its unfertilized counterpart, the walls of fertilized earlywood fibers

Table 1.—Mean strength properties of pulps produced from fertilized and unfertilized red pine wood

Property	Unrefined pulp			Refined pulp		
	Fertilized	Control	F minus C	Fertilized	Control	F minus C
Burst factor	32	44	- 12	70	70	± 0
Breaking length, m	5575	6573	-998	10,022	9538	+484
Tear factor	165	141	+ 24	62	63	- 1

Source: Siddiqui (1970).

were thicker than those of the controls. Apparently the thickening of earlywood fiber walls lowered the collapsibility of the unrefined pulps and thus caused a decrease in burst and breaking length. Concurrently, the thicker-walled fibers produced an improvement in tearing strength (table 1). Refining, however, overcame the increased collapse resistance of the fertilized pulps and the resultant strength properties were consistent with observed wood properties.

A detailed examination of the anatomical characteristics of wood taken from the same study plots, but from different trees, supports our explanation (Gray 1970). The mean double-wall thickness of earlywood fibers from fertilized mate-

rial was approximately twice that from unfertilized material (fig. 3). The walls of latewood fibers from fertilized wood were 20 percent *thinner* than controls, however; and as a result the fertilized wood was much more homogeneous with respect to wall thickness than was unfertilized wood.

WOOD UNIFORMITY: DOUGLAS-FIR

A similar trend toward wood uniformity was observed in Douglas-fir that had been fertilized with 300, 150, and 100 pounds per acre of N, P, and K respectively (Megraw and Nearn 1972). Wood density profiles developed from X-ray

Figure 3.—Relationship between double-cell-wall thickness of red pine tracheids and distance from pith. All tracheids measured were extracted from stem intervals formed after the date of fertilization treatment. From Gray (1970).

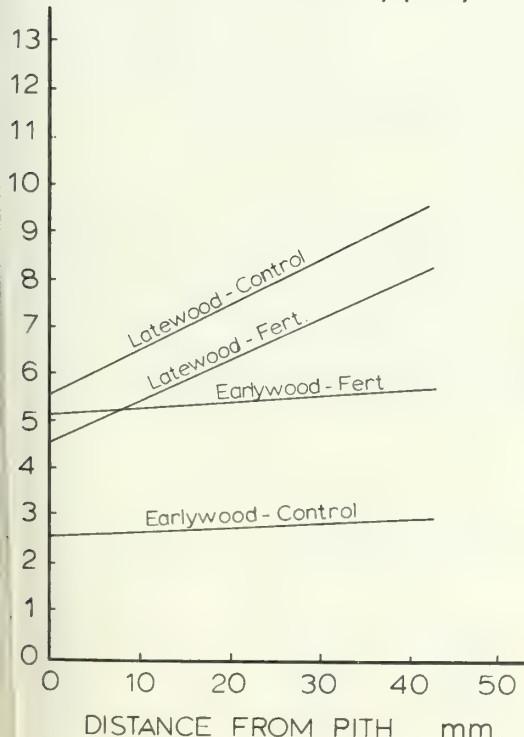
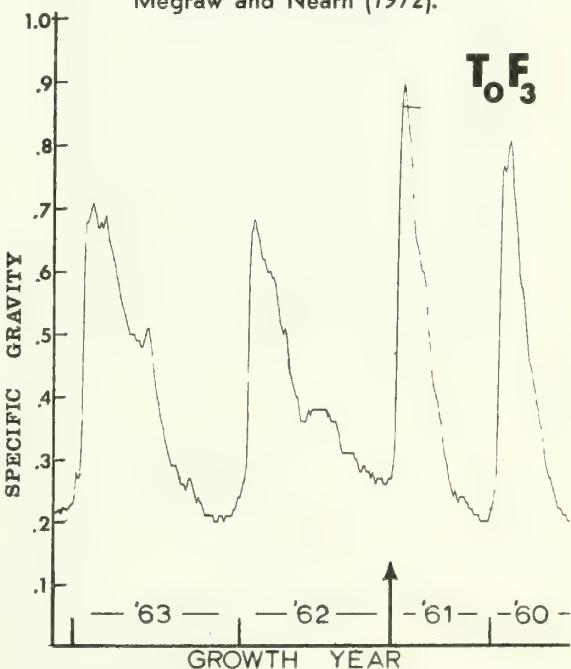


Figure 4.—Within-ring density profile of a Douglas-fir increment core, including two annual increments before and after treatment. $T_0 F_3$ signifies application of a calibration thinning and a fertilization treatment of 300, 150, and 100 pounds per acre of N, P, and K, respectively, in 1962. From Megraw and Nearn (1972).



analysis of increment cores demonstrated that fertilization resulted in increased homogeneity within annual increments. Lower maxima for latewood specific gravity and more wood of intermediate density are evident in figure 4. Composite wood specific gravity was not altered by fertilization, though it was noted that the normal upward trend in specific gravity for 16- to 18-year-old trees was not evident.

An independent but uniquely complementary study of the pulping characteristics of wood from older (45- to 52-year-old) Douglas-fir that had been fertilized with 400 pounds per acre of N reflected similar uniformity changes (*Siddiqui et al. 1972*). During the 7 years immediately following fertilization, a mean volume increase of 74 percent, relative to control trees, was accompanied by a specific gravity decrease of approximately 10 percent. However, the negative impact of this specific gravity decrease on volume-based pulp productivity was halved by an increase of about 2 percent in pulp yield per unit weight of wood.

Contrasts between strength properties of refined pulps from fertilized and unfertilized woods were strikingly similar to those of red pine (tables 1 and 2). Breaking lengths increased with fertilization and, though the specific gravity of fertilized wood was lower, no loss in tearing strength was evident. Collectively, these factors again suggested that fertilization had the effects of: (1) thickening earlywood fiber walls, (2) reducing the thickness of latewood fiber walls, and (3) increasing the proportion of earlywood

(decreasing the proportion of latewood), all of which increased wood uniformity.

Limited confirmation of these trends was gained by measuring cell-wall components on electron micrographs. The mean secondary wall thickness of earlywood fibers increased approximately 20 percent in response to fertilization while the same characteristic in latewood decreased 6 percent. A net increase in the relative amount of cellulose-rich secondary wall present in the fertilized wood probably contributed to the higher pulp yield from that wood. Additional and more comprehensive confirmation is provided by the work of Megraw and Nearn (1972).

CONCLUSION

The trends toward wood uniformity are decidedly favorable for wood quality vis-a-vis the pulp and paper industry. Losses in specific gravity and concomitant losses in pulp yield per unit volume of wood can be minimized or offset by increases in the thickness of earlywood fiber walls. This same fertilizer-induced thickening process can also stabilize or increase pulp yield per unit weight of wood.

In both the red pine and Douglas-fir instances, tearing strength and burst factor levels were maintained while improvements in breaking length were realized as a result of fertilization. Fiber and paper qualities were improved by fertilization, coincident with substantial improvement in volume growth.

Table 2.—Mean strength properties of refined pulps produced from fertilized and unfertilized Douglas-fir wood

Property	Fertilized	Control	F minus C
Burst factor	75	75	± 0
Breaking length, m	10,430	10,105	+325
Tear factor	111	108	+ 3

Source: Siddiqui *et al.* (1972).

Though this uniformity trend is certainly not universal, the identification of species, site, and treatment combinations to which it does apply is desirable.

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FERTILIZATION OF ADULT AND JUVENILE HARDWOODS IN ONTARIO

by R. C. ELLIS and F. W. von ALTHEN, Research Scientists,
Canadian Forestry Service, Great Lakes Forest Research
Centre, Sault Ste. Marie, Ontario.

FERTILIZATION OF ADULT HARDWOODS

by R. C. Ellis

ABSTRACT. Fertilization and thinning are being used to rehabilitate hardwood woodlots of southern Ontario for the production of high-grade hardwood lumber. Variable conditions of tree quality, species composition, and age necessitate that experimental treatments be evaluated on the basis of individual tree responses. A method is described for the selection of trees and their allocation to treatments according to a competition index. Soil perfusion techniques were used to assay the degree to which different levels of nitrogenous fertilizer might increase the amount of nitrogen available to the trees from forest soils with brown forest to gray-brown podzolic profiles.

INTRODUCTION

IN CANADA the heavy hardwoods exhibit their greatest variety and best growth in southern Ontario. This is near the centre of the range of sugar maple (*Acer saccharum* Marsh.) and in the northern ranges of white ash, (*Fraxinus americana* L.), black cherry (*Prunus serotina* Ehrh.), and black walnut (*Juglans nigra* L.).

As the result of a varied history of clearing and exploitation, the remaining stands of mature hardwoods are degraded, and most of the hardwood re-

source is in the form of regrowth stands that are less than 100 years old. In consequence the wood-using industries are becoming short of home-grown quality hardwoods.

The principal objective of the Canadian Forestry Service's program is to increase the supply of quality hardwoods: in the short term, by improving the growth of existing young stands; in the long term, by establishing desirable tree species, either in plantations or by enrichment planting beneath existing stands. A secondary objective, which is increasing in importance, is the growing

of hardwoods for amenity purposes. Fertilization is being carried out in both aspects of this program.

THE PROBLEM

Growing heavy hardwoods differs from growing many other species in that one is concerned with quality rather than quantity. The amount of veneer or first-class lumber that is produced by a degraded stand may bear little or no relation to the gross weight of fiber contained in the stand; therefore one must consider the potential growth, and hence the response to treatment of individual trees.

The heterogeneous species composition and stocking of most stands in southern Ontario present problems in the evaluation of responses to treatments. One has to assess the effect of silvicultural treatments upon individual trees that are growing in stands where species composition and age-class distribution are largely the effect of a complex history: where the density of stand that represents full stocking varies from point to point, and is dependent upon additional factors such as soil depth, texture, stone content, position on slope, and bedrock configuration. The main problem is to relate response to the level of treatment and yet achieve a manageable number of replicates.

A fertilizer x thinning experiment was made in hardwood woodlots. In young stands a 3^2 factorial design was used that contained 5 trees per treatment combination, or 45 trees per block; it was repeated in six woodlots of varying age. In two older stands only the fertilizer treatment was carried out: 15 trees per treatment, for 45 trees per block, in each woodlot.

All the stands are in Grey County, Ontario, and are situated on soils formed from calcareous glacial till. The soil profiles are uniform and classified as brown forest or gray-brown podzolic intergrades in which the slightly acid A₁ horizon of

about 10 cm. depth grades rapidly into a slightly alkaline B₁ horizon. They are well drained. The steps taken to overcome the variable conditions presented by the small privately owned woodlots are outlined in some detail below.

Characterization of the Sample Trees

Selection.—The individual tree was the unit of treatment. A tree was considered if an examination of its bole and crown indicated a high probability of its developing into a veneer log or first-class saw log.

Observations of hedgerow trees suggested that a tree had a depressing effect upon adjacent field crops that extended from the tree to a distance equal to 1½ times the radius of its crown. Therefore it appeared reasonable to assume conversely that a tree would be relatively unaffected by treatments that were applied at distances greater than 1½ crown radii from its stem. Measurements made upon more than 100 dominant and codominant trees revealed that for sugar maple the diameter at breast height in inches, within the range 5 to 13 inches, was almost equal to the radius of the crown in feet. In practice it was assumed that interaction between two trees would be negligible if they were separated by a distance equal to twice the sum of their crown radii; for example, two trees of 10 inches d.b.h. should be separated by at least 40 feet.

Upon these premises 45 trees were selected from each of 8 stands. Each stand was predominantly of one age class, and the mean d.b.h. of sample trees per stand varied from 6 to 14 inches (table 1).

Competition index.—In stands of heterogeneous structure and growing conditions, the release by thinning of individual trees to a uniform standard cannot be effected by a uniform reduction in basal area either on an absolute or on a percentage basis, or on the basis of thinning to a given radius. Thinning seeks to reduce competition to the

Table 1.—Characteristics of the experimental stands
[All on well-drained, upland, calcareous soils]

Stand No.	Age	Species	Land form	Mean d.b.h. sample trees
	Years			Inches
1	30	Sugar maple	Till plain	6.2
2	35	Sugar maple	Till moraine	6.6
3	40	White ash (black cherry, sugar maple)	Drumlin	7.4
4	40	Black cherry (white ash, sugar maple)	Drumlin	7.6
5	65	Sugar maple (beech, elm)	Till plain	9.6
6	85	Sugar maple (white ash)	Till plain	12.5
7	(^m)	Sugar maple	Till moraine	13.5
8	(^m)	Sugar maple (red maple, basswood, black cherry)	Till plain	13.9

^mMature.

selected tree, a competition that depends upon the relative size and spatial distribution of the competitors and upon the density of stand that represents full stocking in the vicinity of the selected tree.

It was necessary to make several assumptions:

1. That in a more or less even-aged stand that had been undisturbed for at least 10 years, the level of effective competition was relatively uniform throughout.

2. That the competitive effect of a neighboring tree upon a sample tree was proportional to

$$\frac{(\text{d.b.h.})^2 \text{ of competing tree}}{(\text{d.b.h.})^2 \text{ of sample tree}} = \frac{d^2}{x^2}$$

3. That the extent to which the zones of influence of adjacent trees overlap is inversely related to the square of the

$$\text{distance between them } \frac{1}{D^2}$$

4. That the effects of neighboring trees upon the sample tree are additive.

The competitive effect of a neighboring tree upon a sample tree was considered to be proportional to

$$\frac{d^2}{x^2 \times D^2}$$

and an index of the competition experienced by a sample tree is then given by

$$\sum \frac{n}{1} \frac{d^2}{x^2 \times D^2}$$

To make these and subsequent calculations, each sample tree was made the center of a plot, and the position of each neighbor was mapped within a radius equal to twice the crown diameter of the sample tree. Beyond this distance a tree was included where its distance was less than the sum of the diameters of its own and the sample tree's crowns. From these plot maps a competition index was calculated for each sample tree.

(It was realized that competitive effect does not increase indefinitely with diminution in D, because this would give undue weight to small suppressed trees growing very close to the sample tree. Therefore D (in feet) was assumed to diminish until it equalled x (in inches), and was then constant at this figure: for example, the competitive effect of a tree growing very close to the sample tree was considered to be no greater than it would have been had its axis been located directly beneath the periphery of the crown of the sample tree.)

Allocation to treatments.—In each replicate the 45 trees were arrayed by competition index. For thinning x fertilizing

treatments, the array was divided into 5 groups of 9 trees each, and from each group a tree was assigned at random to each treatment. When fertilizing was the only treatment, each array was divided into 3 groups of 15 trees each, and 5 trees from each group were assigned at random to each treatment. Insofar as it was reflected in the competition index, variation in the conditions of growth of

the trees was thus effectively distributed among the treatments.

Characterization of the Fertilizer

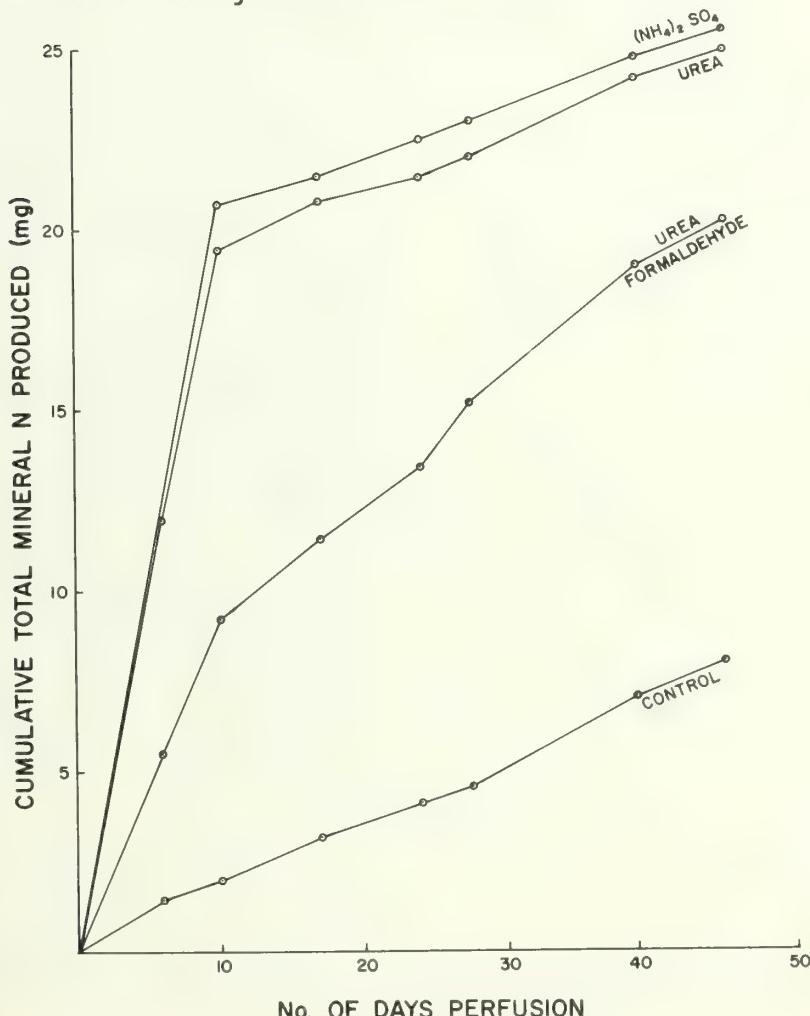
Choice of fertilizer.—In northern forest zones, responses to nitrogenous fertilizer are commonly reported. Mitchell and Chandler's (1939) oft-quoted study indicated a marked response by several hardwood species to nitrogenous fertilizer but

Figure 1.—Cumulative total of mineral nitrogen produced as NO_3^- from maple woodlot soil amended with three nitrogenous fertilizers.

UREA FORMALDEHYDE: 30.0 mg. N added

$(\text{NH}_4)_2\text{SO}_4$: 21.0 mg. N added

UREA : 19.4 mg. N added

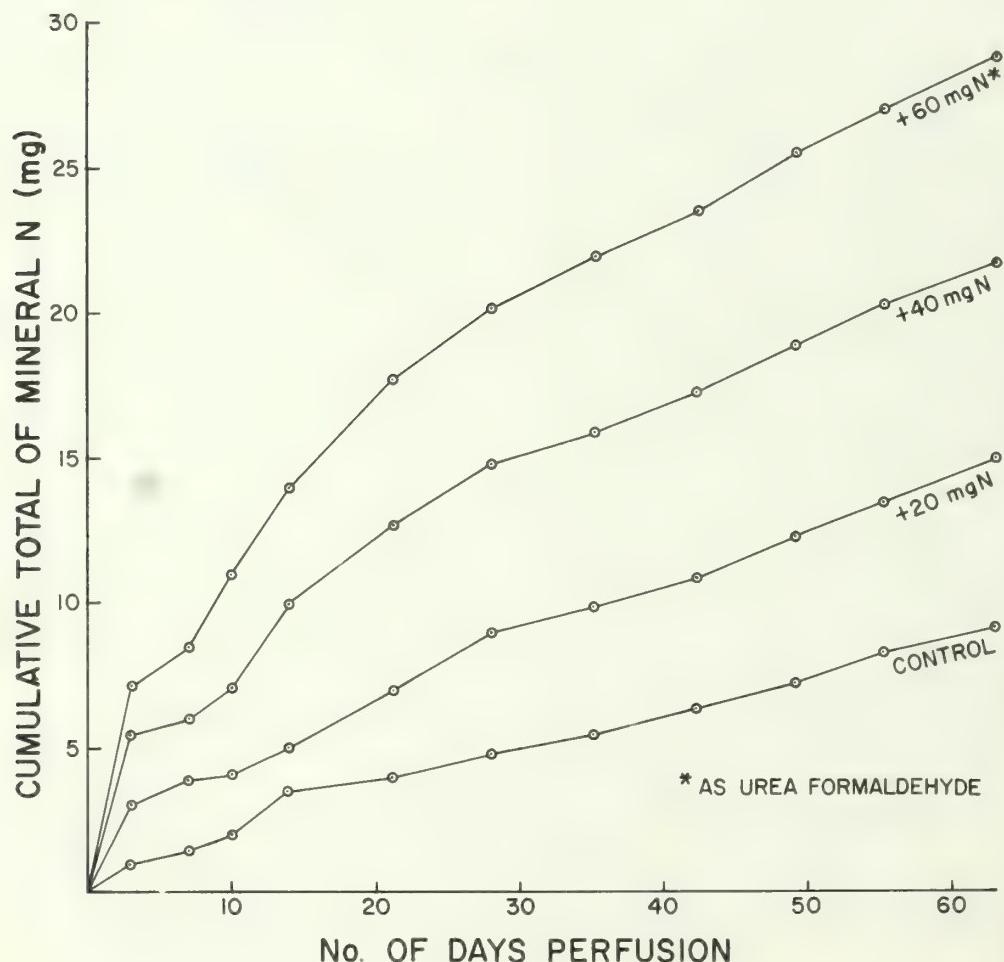


little response to phosphatic or other fertilizers. Neely, Himelick, and Crowley (1970) reached a similar conclusion and, further, found little difference in overall response to N applied either as ammonium nitrate, ammonium sulphate, urea, or urea formaldehyde. A preliminary sampling of foliage from five stands in southern Ontario indicated that the rate of growth of sugar maple was more closely related to the foliar concentrations of N and Mn than to those of P, K, Ca, Mg, Fe, or Zn. Therefore it was decided to investigate first the effect of

adding nitrogenous fertilizer to the stands.

Perfusion experiments.—The interaction between A₁ horizon soil and three nitrogenous fertilizers was studied by means of a perfusion apparatus. Two hundred g. of a composite sample of moist soil from a mature stand of maple was put into each of eight tubes. (The soil had been frozen since its collection in September, 3 months before.) Ammonium sulphate, urea, and urea formaldehyde were each added to two tubes of the eight, and two served as control. Perfus-

Figure 2.—Cumulative production of mineral nitrogen as NO₃ from maple woodlot soil amended with three levels of urea formaldehyde.



sion with water was continued for 7 weeks. At intervals of a few days the perfusate was drained and analyzed, and replaced with fresh water. The net rate of formation of nitrate from the three fertilizers is shown in figure 1.

It was found that 90 percent of the N in ammonium sulphate and urea had been converted to nitrate after 10 days, as opposed to only 23 percent of that from urea formaldehyde. Nitrate formation from urea formaldehyde proceeded at a fairly uniform rate for the duration of the experiment, whereas after 10 days there was no further production of nitrate from the other two fertilizers. From this it was concluded that on these soils urea formaldehyde could be the most satisfactory compound to use. Leaching of nitrate during spring runoff would probably diminish the effectiveness of the more easily converted fertilizers, whereas, from urea formaldehyde, mineral nitrogen could be released continuously throughout at least the first growing season.

In a second perfusion experiment, three quantities of urea formaldehyde were added in duplicate to tubes of soil taken from a stand of mature maple. (This second sample of soil had also been kept frozen since its collection 4 months before.) The tubes were perfused for 63 days, during which time the perfusate was periodically drained and analyzed for nitrate. The pattern of net nitrification is shown in figure 2.

In each case a flush of activity during the first 3 days converted about one-tenth of the fertilizer N to nitrate. Over the 9 weeks of the experiment, nearly one-third of the N in the fertilizer appeared as nitrate, and the amount of nitrate produced in excess of that of the control was almost exactly proportional to the amount of fertilizer that was added (fig. 3). During the past 35 days of the experiment nitrate was produced at a constant rate in each tube: that rate, less the control rate, was again propor-

Figure 3.—Mineral nitrogen produced as NO_3^- after 63 days perfusion of a maple woodlot soil with three levels of urea formaldehyde.

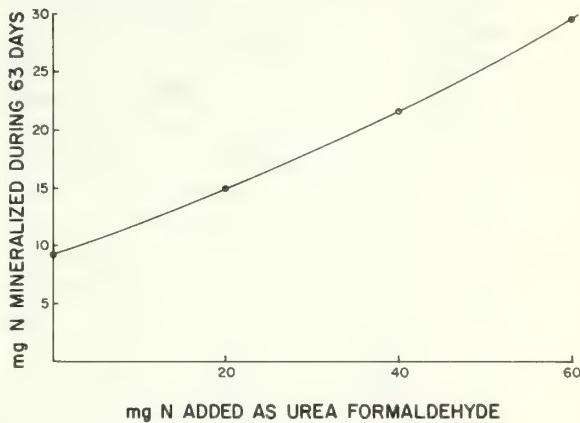
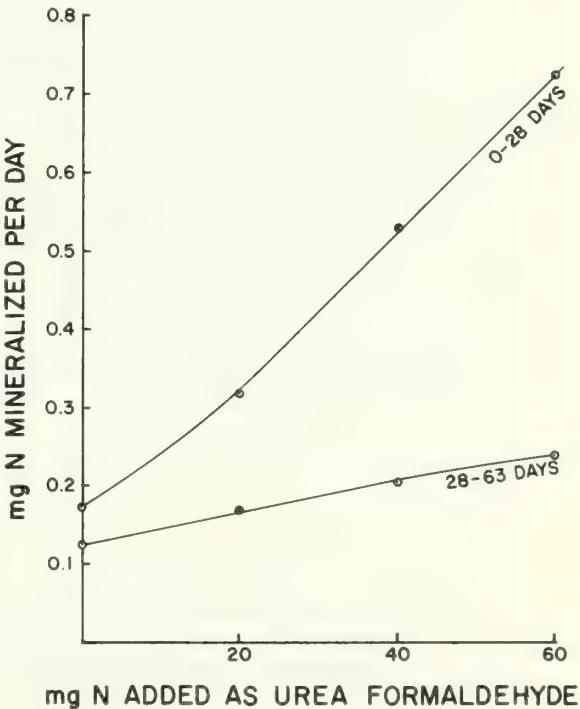


Figure 4.—Rate of production of mineral nitrogen as NO_3^- in mg. per tube per day with three levels of urea formaldehyde.



tional to the amount of fertilizer added (fig. 4).

Rate of fertilizer application.—From the perfusion experiments it is possible to calculate the proportion by which a given amount of urea formaldehyde fertilizer should increase the net amount of nitrate produced in this soil. Implicit in this is the reasonable assumption that, though the absolute rate of nitrate formation will vary with soil temperature, soil moisture, and season of the year, the relative rates of net nitrate production in fertilized and unfertilized soils will remain fairly constant.

Each tube contained nearly 130 g. of soil (air-dry). The addition of 30 mg. of nitrogen as urea formaldehyde doubled the net amount of nitrate that was formed over an interval of 9 weeks, and at the end of this period the rate of net nitrate production was still 50 percent greater than that of the control. The depth of the active (A_1) horizon of the soil beneath these hardwood stands was about 10 cm.; bulk density of the horizon averaged 1.2; rock and cobble content was estimated at 15 percent of the volume. The weight of the active horizon of the soil was estimated to be almost 840,000 kg./ha., or 750,000 lb./acre. By proportion, it seemed possible that the addition of 520 lb./acre (590 kg./ha.) of urea formaldehyde could effect a doubling of the mineral N that was available to the trees during the ensuing 2 months and a 50-percent increase for some time thereafter. This distant extrapolation was accepted in the absence of any more reasonable basis of calculation. The rates of application adopted were 520 and 260 pounds of urea formaldehyde (33 percent N) per acre.

Field Treatments

Thinning.—Thinning consisted of felling or sap-ring neighboring trees to reduce the competition index of the sample trees by a given percentage. Different

degrees of thinning were first simulated on the plot maps. It was found that a 50-percent reduction in the competition index was usually achieved by the removal of three or four codominant near neighbors of the sample tree. A 75-percent reduction in the competition index left the sample tree with its crown virtually free of contact with those of its neighbors. A large number of simulations in each of the stands to be thinned indicated that, for silvicultural purposes, the approach was a realistic one and generated very few anomalies. The two thinning grades adopted were a 50-percent and a 75-percent reduction in the competition index.

Trees to be removed were selected initially on the plot map. If, later in the field, it was decided to retain a tree for silvicultural reasons, it was replaced on the condemned list with a tree, or trees, of similar competitive effect.

Thinning was completed by early August 1970. Most of the sap-rung trees were dead by July 1971, and those that still survived were then felled with a chainsaw. In stand 6, many trees were of a utilizable size, and these were felled and extracted in October 1970.

Fertilizing.—Urea formaldehyde fertilizer was applied by hand in early April 1971. At this time most of the snow had melted, but a light cover remained on 25 to 90 percent of the ground surface. This facilitated an even spread of fertilizer. It was placed on the surface of the ground around the tree on a radius equal to $1\frac{1}{2}$ times the crown radius of the tree. Thus at a rate of application of 260 lb./acre a tree of 6 inches d.b.h. received 1.5 pounds, and a tree of 14 inches d.b.h. received 8.5 pounds.

Response to Treatment

Growth in diameter.—A dendrometer band was installed on each sample tree at the time of fertilizer application. Readings were taken at intervals of 3 weeks

until October 1971 and were recommenced in early May 1972.

Although the treatments were not completed until April 1971, some trends became apparent within 5 months of applying the fertilizer. In stands 7 and 8 (unthinned), the growth of the heavily fertilized trees increased by 16 percent and 19 percent respectively over that of the control trees. However, variation was such that these differences did not reach a statistically significant level.

In the thinned x fertilized woodlots, no clear trends had appeared by the end of

the first growing season. However, the ash in stand 6 showed a significant response to thinning ($F = 5.10$, cf. 4.11 for 2.5 percent probability), and the cherry of stand 4 showed a significant response to fertilizer ($F = 3.61$, cf. 3.26 for 5 percent probability).

Increase in leaf weight.—In stands 2 (maple), 3 (ash), and 4 (cherry) two branches of approximately $\frac{1}{2}$ inch in diameter were collected from the upper half of the crown of each sample tree during late August 1970 and again in 1971. Successive groups of leaves from

Table 2.—Effect of treatment in increasing the weight of leaves in three hardwood species during the first season

Ratio of mean squares	Species			F(5%)
	Sugar maple	White ash	Black cherry	
Thinning (A) error	0.07	0.11	0.92	3.11
Fertilizing (B) error	.43	8.88 ^a	.74	3.11
A + B error	2.41	.43	.17	2.48

^aSignificant at the 1-percent level of probability.

Table 3.—Effect of treatment in increasing the concentration of nitrogen in the leaves of three hardwood species during the first season

Ratio of mean squares	Species			F(5%)
	Sugar maple	White ash	Black cherry	

ANALYSIS OF DIFFERENCES AMONG 1971 CONCENTRATION LEVELS (2 BRANCHES PER TREE)

Thinning (A) error	1.54	0.84	1.49	3.11
Fertilizing (B) error	2.50	.56	.95	3.11
A + B error	1.87	.54	1.03	2.48

ANALYSIS OF DIFFERENCES BETWEEN 1970 AND 1971 CONCENTRATION LEVELS (BY TREES)

Thinning (A) error	1.01	1.81	1.65	3.26
Fertilizing (B) error	13.14 ^a	4.02 ^b	3.50 ^b	3.26
A + B error	2.50	.91	.44	2.63

^aSignificant at the 1-percent level of probability.

^bSignificant at the 5-percent level of probability.

each branch were oven-dried at 105°C., and the mean oven-dry weight per leaf was then calculated for each branch. Subsamples were taken for chemical analysis.

The species differed among themselves in this response. The weight of both maple and cherry leaves appeared to be unaffected by either fertilizing or thinning, but ash showed a large and highly significant increase in the weight of its leaves after being fertilized (table 2).

Increase in Foliar Nitrogen levels

An analysis of variance of the simple 1971 data indicated only a slight and nonsignificant effect of the treatment for all species (table 3). The analysis of variance was performed on the differences effected in levels of N within trees by treatment in 1970 and 1971. The sensitivity of the analysis was thereby improved, and all three species showed sig-

nificant increases in foliar concentration of N as a result of fertilizer treatment.

DISCUSSION

The main points of interest in this work lie in the attempt made to ensure that a treatment of uniform probable effect could be applied to single trees that differed appreciably in their conditions of growth. In terms of tree diameter growth, it is too soon to tell whether or not this was achieved. However, after one growing season, mean differences between treatments of as little as 5 percent in leaf size and 7 percent in foliar N level attained significance at the 5-percent level of probability. It may be anticipated that nitrogenous fertilizer, in increasing both the size of the leaves and their concentration of N, will effect an increased rate of growth in tree diameter in ensuing growing seasons.

FERTILIZATION OF JUVENILE HARDWOODS

by F. W. von Althen

ABSTRACT. In a series of studies, plowing and disking the planting site, followed by effective weed control for the first 3 years after planting, were found to be prerequisite to the successful establishment of hardwood plantations in southern Ontario. To increase seedling growth during the critical establishment phase, N-P-K fertilizers were applied to the soil surface at time of planting. However, these treatments failed to produce consistent increases in growth, and further studies are now under way. Until more promising results are obtained, fertilization of new hardwood plantations cannot be recommended.

BACKGROUND

During the last decade, interest in hardwood afforestation has greatly increased in southern Ontario because of a dwindling supply of high-quality timber and a growing appreciation of the environmental and aesthetic values of hardwood trees. Southern Ontario is a predominantly agricultural area, and forests are generally restricted to sites unsuited to agriculture. Although some clearing of woodlots is still under way in the most productive agricultural regions, larger farmland areas of marginal productivity and lands unsuited to the economic use of farm machinery are being removed from agriculture. This is the land that is generally available for afforestation. Though most of the available land will not support quality hardwood growth, many tracts contain small areas that are capable of growing good hardwood timber. These are the sites on which hardwood planting should be concentrated.

HARDWOOD PLANTATION SURVEY

To determine the relative importance of factors affecting hardwood establishment and growth in southern Ontario, in 1963-64 we sampled 296 plantations ranging in age from 10 to 85 years (*von Althen 1965*). The results of this survey showed that soil texture, depth to C-horizon, and drainage were the three most important factors affecting hardwood growth. Although plantation histories were difficult to verify, several owners distinctly recalled having fertilized their plantations at time of planting at the same intensity as their adjacent crops. Although each plantation received a uniform broadcast application of fertilizer, large variations in growth occurred in all plantations.

Close examination of soils nearly always revealed variations in growth caused by changes in either soil texture, depth to C-horizon, or drainage. In no instance could it be ascertained that ferti-

lizer, applied at time of planting, had maintained growth on a site where one of these major soil factors was unfavorable to the growth of the planted species.

FIELD EXPERIMENTS

The hardwood species commonly planted in southern Ontario are white ash (*Fraxinus americana* L.), red oak (*Quercus rubra* L.), basswood (*Tilia americana* L.), silver maple (*Acer saccharinum* L.), black walnut (*Juglans nigra* L.), sugar maple (*Acer saccharum* Marsh.), and black locust (*Robinia pseudoacacia* L.). During the early years after planting, seedlings of most of these species are highly susceptible to damage from browsing by rabbits, stem girdling by mice, and damage by frosts as late as the beginning of June. Any treatment that increases growth will reduce the period during which a new plantation is vulnerable to such injuries, and this will increase the probability of successful establishment.

To determine the relative importance of site preparation, chemical weed control, and fertilization on the establishment and early growth of sugar maple, red oak, basswood, black locust, silver maple and white ash, seedlings were set out in a nonreplicated pilot experiment in the spring of 1964 near Richmond Hill, Ontario. The planting site was a former hayfield with a soil classified as Cashel clay (a uniform neutral clay over compact clay till at a depth of 2 feet). The pH of the plow layer was 7.2, and the organic matter content 3.5 percent. Site preparation consisted in either plowing and disking in autumn prior to spring planting or removing a scalp 18 inches in diameter at time of planting, at each prospective planting spot. Granular simazine was applied either alone or in combination with the fertilizer in dosages of 3, 6, or 12 lb./acre of active ingredient. Ammonium nitrate, triple superphosphate, and potassium sulphate were broadcast

in combination with the herbicide on the soil surface shortly after planting in the following amounts (lb./acre of active ingredient): level A: N - 75, P - 40, K - 40; level B: N - 150, P - 80, K - 80; level C: N - 300, P - 160, K - 160.

The results of this study showed that no single treatment assured successful establishment (*von Althen 1970*). However, plowing and disking of the total plantation area proved to be prerequisite to the success of the herbicide and herbicide-plus-fertilization treatments. In all plots where site preparation was restricted to the removal of a scalp 18 inches in diameter, the herbicide and herbicide-plus-fertilization treatments failed to assure planting success. In the plowed and disked plots, fertilization at level C nearly doubled height growth of white ash during the first 3 years, and this advantage increased during the next 5 years (table 4).

Fertilization at level C also increased height growth of silver maple and black locust; but all sugar maple, basswood, and red oak seedlings were so severely browsed by rabbits that an assessment of growth responses was impossible.

The results of this preliminary trial were encouraging, and in the spring of 1969 we established two sets of 3³ factorial fertilizer experiments near Parkhill, Ontario. In the first set, 972 seedlings each of 1+0 black walnut, 2+0 basswood, and 2+0 red oak were planted in an abandoned field with a soil of deep, well-drained, fine sandy loam (Fox fine sandy loam). The pH of the plow layer was 6.4, and the organic-matter content was 2.4 percent.

In the second set, 972 seedlings each of 1+0 walnut and 2+0 silver maple were planted in an abandoned field of slightly eroded, imperfectly drained loam (Parkhill loam). The pH of the plow layer was 7.2, and the organic-matter content was 3.2 percent.

Both fields were plowed and disked in the summer before spring planting

Table 4.—Average 3- and 8-year height growth of three species planted in plowed and disked plots, in feet

Species	Control	Three-year height growth			Eight-year height growth					
		Herbicide only	Herbicide plus fertilization ^a	Level A	Control	Herbicide only	Herbicide plus fertilization ^a	Level A	Level B	Level C
Black locust	3.4	8.1	7.5	7.4	10.0	15.5	15.5	13.5	18.5	
Silver maple	.5	4.1	4.5	5.3	5.2	9.0	10.5	12.0	12.0	
White ash	.7	2.4	3.5	3.5	4.4	6.5	12.5	10.0	13.0	

^aFertilization (lb./acre of active ingredient):

Level	N	P	K
A	75	40	40
B	150	80	80
C	300	160	160

Shortly after planting, ammonium nitrate, triple superphosphate, and potassium sulphate were broadcast singly and in combination in the following amounts (lb./acre of active ingredient): N - 0, 100, 200; P - 0, 50, 100; K - 0, 50, 100. Simazine 50W was sprayed over the total area shortly after planting and in early spring of the second and third growing seasons in the following dosages (lb./acre of active ingredient): walnut 8, 4, 4; silver maple 6, 3, 3; red oak and basswood 4, 4, 4.

After three growing seasons, average height growth on the fine sandy loam was 3, 2.9, and 3.1 feet respectively for walnut, basswood, and oak. On the loam the average height growth was 3.1 feet for walnut and 6.7 feet for silver maple. Differences in height growth between treatments within individual species were nonsignificant on both soils, indicating failure of all fertilizer treatments to improve height growth. The results of foliar analyses of samples collected on both soils in late summer of the first and second growing seasons also showed no significant differences in N, P, or K concentrations between treatments within individual species on the same soil (table 5).

Failure of the fertilization treatments to improve growth cannot be fully explained. However, the low concentrations of P in all leaf samples and K in all but the basswood leaves indicate possible P and K deficiencies (Finn 1966). Since only N, P, and K were examined, limited availability of other minerals might have prevented or retarded P and K uptake. It is also possible that the small root systems of the newly planted seedlings were unable to utilize the fertilizer until most of the nutrients were lost by conversion into insoluble form, gaseous exchange, or leaching.

Table 5.—Average foliar N, P, and K by site, species, and year of sampling

Site	Species	N		P		K	
		1st year	2nd year	1st year	2nd year	1st year	2nd year
Sandy loam	Black walnut	3.14	3.12	0.117	0.095	0.997	1.25
	Basswood	2.51	2.81	.112	.070	1.19	1.94
	Red oak	2.38	2.47	.091	.102	.747	.710
Loam	Black walnut	2.97	2.91	.103	.097	.803	.744
	Silver maple	2.91	2.73	.088	.086	.628	.677

DISCUSSION

Haley (1966) stated that it is most unlikely that the returns from fertilization at time of planting will cover the high costs involved, except in those instances where the establishment of a crop would be impossible without fertilization. If hardwood planting is restricted to good planting sites with deep, moist, but well-drained soils, there is little need for fertilization, because site preparation and weed control, properly applied, will generally guarantee successful establishment and satisfactory early growth (*von Althen 1971*). However, interest in hardwood planting has increased greatly during the last decade, and hardwoods are often planted on sites that do not meet the foregoing criteria. Fertilization may be necessary on these marginal sites.

To date, the results of our fertilization experiments have not been encouraging. We strongly suspect the main reason is that the fertilizers were applied to the soil surface at time of planting to minimize treatment costs. However, newly planted seedlings—with their small, bunched, and often mutilated root systems—seem poorly equipped to utilize the fertilizer before the nutrients are either

converted into insoluble form or lost by gaseous exchange or leaching. The favorable results obtained in sand culture studies (*Broadfoot and Ike 1968*) and soil-pot tests (*Dickson 1971; Phares 1971*) as compared to less successful field experiments (*McComb 1949*) seem to support this hypothesis.

We have found that white ash responds more readily to surface-applied fertilization than any of the other species tested. Presumably this is due primarily to the high N requirement of the species (*Mitchell and Chandler 1939*); but the relatively large, fibrous root system of white ash seedlings may be a contributing factor.

Mixing fertilizer with the soil appears to be economically feasible as plowing and diskng of the total plantation area are essential, and fertilizer could be incorporated during the diskng operation. We are presently investigating this approach as well as testing the effects of time of fertilizer application on nutrient uptake and seedling growth.

Until more promising results are obtained, fertilization of new plantations will remain economically unattractive, and it is recommended that planting be restricted to sites of proven productivity.

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FOREST FERTILIZATION IN EASTERN CANADA, WITH EMPHASIS ON NEW BRUNSWICK STUDIES

by H. H. KRAUSE, *Associate Professor, Faculty of Forestry, University of New Brunswick, Fredericton, New Brunswick.*

ABSTRACT. Although the allowable cut is far in excess of wood consumption in eastern Canada, a strong interest in forest fertilization developed during the 1960's. Main emphasis was placed on experimentation with fertilizers on small experimental plots, and major research programs were developed by the Pulp and Paper Research Institute of Canada, the Canadian Forestry Service, provincial governments, and universities. Although few results have been published, it has become clear that N shortage is commonly limiting growth in pole-size and maturing conifer stands, and that substantial growth increases can be obtained with addition of fertilizer N. Under certain site conditions tree growth may also be improved by addition of K or P.

PHYSIOGRAPHIC AND FOREST REGIONS OF EASTERN CANADA

THE TERRAIN now being found suitable for industrial forestry is located within four physiographic regions: (1) the Appalachian Region, including the Atlantic provinces and the Gaspé Peninsula of Quebec; (2) the St. Lawrence Lowlands; (3) the rugged Laurentian Highlands at the southeastern fringe of the Canadian Shield; and (4) the Abitibi and Severn Uplands, which are a part of the interior portion of the Canadian Shield. The Shield area is characterized by thin surficial deposits consisting of glacial drift derived mainly from gran-

ite bedrock. The Abitibi Uplands include the well-known clay belts, which represent glacial lake bottoms.

The prominent soils of eastern Canada belong to the podzolic (Spodosol) and luvisolic (Alfisol) orders. Within the Appalachian and Laurentian Highland regions, characteristic great groups are humo-ferric and ferro-humic podzols (Orthods). Soils developed from granite till and outwash in the Abitibi and Severn Uplands also belong to the great groups of ferro-humic and humo-ferric podzols. In the clay belt area of the Abitibi Uplands and on lake-bottom deposits of the Severn Uplands, grey luvisols or grey wooded soils (Typaltalfs) have developed. Soils characteristic of the St. Lawr-

ence Lowlands are grey-brown luvisols (Typudalfs).

The forest vegetation of primary interest to industrial forestry may be subdivided into three types: (1) the Acadian forest; (2) the Great Lakes-St. Lawrence forest; and (3) the boreal forest, which forms a continuous band from Newfoundland through Quebec and Ontario (Rowe 1959).

Best known probably is the Great Lakes-St. Lawrence forest type with its mixed stands of white pine (*Pinus strobus* (L.), hemlock (*Tsuga canadensis* (L.) Carr.), white spruce (*Picea glauca* (Moench) Voss), yellow birch (*Betula alleghaniensis* Britton), maples (*Acer saccharum* Marsh. and *A. rubrum* L.), beech (*Fagus grandifolia* Ehrh.), and other species. Red pine (*Pinus resinosa* Ait.) is widely distributed on well and excessively drained sites.

The Acadian forest resembles the Great Lakes-St. Lawrence forest. Its main characteristic is the wide occurrence of red spruce (*Picea rubens* Sarg.) usually in association with balsam fir (*Abies balsamea* (L.) Mill.). Most of the northern hardwoods are found in this region. Red pine is less frequent than in the Great Lakes-St. Lawrence region.

The characteristic species of the boreal forest are black spruce (*Picea mariana* (Mill.) B.S.P.) and white spruce. Other common conifer species are jack pine, tamarack (*Larix laricina* (Du Roi) K. Koch), and balsam fir. Black spruce forms pure stands on ill-drained as well as on upland soils, and it occurs in association with jack pine on excessively drained soils. The predominantly coniferous stands usually have an admixture of broadleaf species, mainly white birch (*Betula papyrifera* Marsh.) and trembling aspen (*Populus tremuloides* Michx.).

The forest regions of Canada have been subdivided by Rennie (1972a) into eco-units. Criteria used are forest cover, climate, geology, and soils. Forty-five

eco-units have been recognized for eastern Canada. This classification will undoubtedly facilitate description and evaluation of forest-fertilization studies.

FOREST PRODUCTIVITY, ALLOWABLE CUTS, AND WOOD CONSUMPTION

The potential growth of forests varies considerably throughout eastern Canada. Average productivity is highest in the Maritime Region, peak values being reported for Prince Edward Island and New Brunswick (Manning and Grinnell 1971). Growth rates are considerably lower in the boreal forest within the Canadian Shield because of short growing seasons and less productive soils. The allowable cut per unit area is lowest for Quebec. The average allowable cut given per unit area for Ontario is notably higher than the cut for Quebec, probably because a large proportion of the forested area in Ontario consists of the more productive Great Lakes-St. Lawrence type forest and because the clay belt with its more productive soils is included in the region of the boreal forest.

The wood resources are used at variable rates in eastern Canada. In all provinces except Prince Edward Island, the allowable cut exceeds consumption by a substantial margin (table 1). Nova Scotia and New Brunswick utilize less than 50 percent of the allowable cut, and in Ontario the consumption is only slightly more than 25 percent of the allowable cut. Quebec seems to use its forest resources to a fuller extent than most other provinces; primary productivity amounts to approximately 70 percent of the allowable cut.

The average volumes harvested per acre and the theoretical cutting cycles would indicate that provinces such as Newfoundland, Quebec, and Ontario have been working, at least up to 1968, with large reserves of mature timber.

Table I.—Allowable cuts and primary forest production in the various provinces of eastern Canada

Province	Allowable cut on forest land allo- cated to timber production	Primary forest production (average-1964-68)	Average volume harvested per acre	Theoretical cutting cycle
	M cubic feet	M cubic feet	M cubic feet	Years
Newfoundland	145,600	93,158	2,380	140
Nova Scotia	250,000	110,955	1,110	96
New Brunswick	457,000	209,056	1,050	70
Prince Edward Island	3,700	6,199	1,550	131
Quebec	1,346,100	969,584	1,580	251
Ontario	2,271,900	587,174	1,580	283

Source: *Manning and Grinnell 1971*

New Brunswick, with its comparatively high potential productivity, reported the lowest average yield, just exceeding 10 square cunits per acre (1 cunit = 100 cubic feet), and the theoretical cutting cycle is only 70 years. Nova Scotia's yield per unit area and theoretical cutting cycle are only slightly better than those reported for New Brunswick. The low yields in New Brunswick are due to unfavorable age-class distribution. In the case of spruce, the volume in mature and over-mature classes was reduced to 21 percent by 1968, probably as a result of continued and full exploitation of all forest areas.

FOREST FERTILIZATION RESEARCH IN EASTERN CANADA

Despite the fact that allowable cuts exceeded current wood consumption, a strong interest in forest fertilization developed in Canada during the 1960's. Possible reasons were the rapid growth of the wood-using industry during this period, diminishing wood supplies near production centres, and unfavorable age-class distribution. A detailed account of fertilization research and fertilizer use in Canadian forestry was given by Rennie (1972b) in a report to the 8th World Forestry Congress.

In eastern Canada, some industries and one provincial government proceeded with aerial application of fertilizers on an operational trial basis. In total, probably not more than 5,000 acres have been fertilized. The Pulp and Paper Research Institute of Canada, the universities, and especially the Canadian Forestry Service greatly intensified research in forest fertilization and supporting disciplines during the past decade. Although some projects dealt with young plantations, the main thrust was directed at the mineral nutrition of pole-size and maturing pulpwood stands and their response to fertilizer treatments. These stands were predominantly coniferous, and most of them had regenerated naturally.

Research by the Pulp and Paper Research Institute of Canada

Among the oldest field trials with pulpwood stands are the experiments established by the Pulp and Paper Research Institute in cooperation with industries throughout eastern Canada (*Swan 1969*). These trials usually included application of N, P, and K at various rates. Treatments were based on the results of foliar analysis and bioassays involving greenhouse pot cultures with soil

from the area to be treated. To establish a basis for diagnosis of nutrient deficiencies by foliar analysis, extensive sand-culture experiments were carried out with the principal pulpwood species of eastern Canada (*Swan 1970a, 1971*).

Assuming that shortage of N is a principal growth-limiting factor in the northern forest, Weetman and co-workers (1968, 1971, 1972) conducted a series of N fertilization experiments in upland black spruce stands in the southern portions of the boreal forest. These studies were aimed to determine growth responses to urea added at different rates, to detect possible interaction between fertilization and thinning, and to evaluate various N carriers for their suitability in forest fertilization. More recently, work was initiated to determine the interrelationship between foliar N levels and current growth of black spruce and jack pine stands. For this purpose, fertilizer N is added as required to maintain pre-determined foliar N levels.

Research by the Canadian Forestry Service

The Canadian Forestry Service is conducting forest-fertilization research in each of its four centres in eastern Canada. Each program includes extensive field experimentation, usually involving application of N, P, and K at various rates and in different combinations. At least in one case, the effect of liming on the growth of coniferous pulpwood stands was tested, and the use of trace elements is contemplated. The field projects are usually complemented by laboratory and greenhouse studies. Newfoundland soils, for instance, are subjected to intensive greenhouse and laboratory testing.

The Newfoundland and Maritime centres have dealt with N volatilization from urea-treated forest soils (*Mahendrappa 1969; Bhure 1970a*). Using a microbiological approach, the Maritime and Laurentian Centres are investigating N

and organic matter transformations in the forest floor (*Roberge 1970, 1971; Saloniis 1972*). The Maritime and Great Lakes Centres are studying various processes of N cycling in conifer stands (*Mahendrappa and Ogden 1971*). The Laurentian Centre concerns itself with possible effects of fertilizer treatments on insect pests, and the Great Lakes Centre is dealing with mensurational aspects and questions of experimental design in forest fertilization. The comprehensive program of the Great Lakes Centre also includes studies on fertilizer movement, the interrelationship between foliar nutrient levels and tree growth (*Morrison 1972*), and economic aspects of fertilization in pulpwood stands of northern Ontario.

Research by Universities

The Microbiology Department of Macdonald College, McGill University, in co-operation with the Pulp and Paper Research Institute, has studied N relationships in organic surface accumulations of forest soils. Special attention has been given to N transformations in black spruce raw humus (*Chu and Knowles 1966*), hydrolysis of urea (*Roberge and Knowles 1966*), N uptake by black spruce (*Knowles and Lefebvre 1971*), and nonsymbiotic N fixation (*Brouzes et al 1969*).

The Faculty of Forestry of the University of Toronto is experimenting with jack pine in northwestern Ontario. Sandy soil supporting a 49-year-old stand was fertilized by fixed-wing aircraft to determine fertilizer distribution and to evaluate sampling techniques (*Armson 1972*). Additional studies are under way with young plantations to determine interrelationships between fertilizer treatments and spacing of trees and fertilizer herbicide interactions (*Armson and Calvert 1971*).

Research by the Faculty of Forestry and Geodesy of Laval University includes comprehensive field experimenta-

tion with balsam fir and jack pine stands, studies of N losses by volatilization (*Bernier et al. 1972*), studies of the mobility of added and indigenous nutrients in fertilized soil, and an evaluation of the ecological impact of forest fertilization. One study involves amino-acid composition of tree foliage from fertilized soil and its effect on the mortality of jack pine sawflies.

The University of New Brunswick studies aim to determine the responses capability of maturing pulpwood stands to nutrient supplements, to relate fertilization responses to soil and stand conditions, and to improve methods of diagnosing nutrient shortages and predicting fertilization responses. Standardized field experiments were established in the 1960's. Field observations are supplemented by laboratory studies of foliar nutrient contents and N and P relationships in forest floor and B-horizon samples.

Research by Provincial Governments

On the initiative of the Pulp and Paper Research Institute, the provinces of Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan, and Alberta formed an interprovincial task force on forest fertilization. The provinces agreed to establish and maintain a certain number of field experiments in important cover types. Treatments were standardized and included testing of N at three levels, P at two levels, and K a two levels. Growth measurements are to be made 5 and 10 years after treatments. The results are to be evaluated by the Pulp and Paper Research Institute.

Some provinces have conducted forest-fertilization research independently of and prior to the interprovincial program. Ontario, for instance, has experimented with fertilizers and lime in red pine plantations (*Leech 1965, 1967, 1969*), and New Brunswick established several N, P, and K trials in semimature pulpwood stands.

The Nova Scotia Department of Lands and Forest, in cooperation with the Nova Scotia Research Foundation, has carried out forest-nutrition studies involving aerial and hand applications of fertilizers to red pine plantations and red spruce stands of various age classes, and detailed analyses of tree foliage (*Robertson and MacLean 1968*).

Summary of Preliminary Results

Most of the research described here is in an early stage, and few results have been published. Information available to date has shown low to extremely low N levels in foliage of conifers after stand closure and a positive relationship between foliar N and site productivity (*Gagnon 1964, Lowry and Avard 1967*). Black spruce and jack pine stands were shown to respond strongly to N fertilization (*Weetman 1968, 1971; Hoyt 1972*). Although use of urea may lead to N losses by volatilization (*Mahendrappa 1969, Bhure 1970a, Bernier et al. 1972*), it is believed to be the most suitable N carrier for forest fertilization in eastern Canada, except on sites with dry humus layers (*Weetman 1972*). After rapid hydrolysis (*Roberge and Knowles 1966*), urea N was found to remain largely in inorganic form over extended periods of incubation (*Roberge and Knowles 1965; Bhure 1970b*). Field observations by Roberge and Knowles (1965) indicated, however, that substantial quantities of N were immobilized in L, F, and H layers of a black spruce forest floor within 3 years after urea application.

This information is in agreement with foliar N concentrations in black spruce or urea-fertilized soil. N contents of current-year black spruce needles were found to increase strongly during the first growing season after treatment and to decrease rapidly in the following 3 years (*Krause 1971*). Since only a small portion of added N is expected to be taken up by trees (*Knowles and Le-*

february 1971), foliar N levels should have remained high for several years after treatment, had the added N remained in a form in which it is readily available to trees.

Although N fertilization has given the largest growth responses, growth improvements in conifer plantations and naturally regenerated pulpwood stands have also been obtained with other elements, applied separately or in combination with N. Recognizing that sites requiring only N for improved growth certainly exist, Swan (1969) commented that during his 10 years of field experience no situation was found in which N, applied by itself, gave the best results. A naturally regenerated jack pine stand and a white spruce plantation, both on sandy outwash of Quebec, responded to N and K fertilizer. Potassium responses were also obtained with jack pine on abandoned farmland (Gagnon 1969). Black spruce, naturally regenerated, 75 to 85 years old and growing on imperfectly drained soil of northwestern Ontario, responded to addition of P (Swan 1969).

The observed response of conifers to K when growing on outwash soils is in agreement with reports from other locations (Heiberg and White 1951, Heinsdorf 1968), and the positive reaction of black spruce to P on soils with imperfect drainage agrees with observations in New Brunswick (Krause 1971).

Weetman (1962) observed that N shortage existed as a result of raw humus formation also in black spruce stands of eastern Canada, and that such stands are likely to respond to N additions. These early observations from Canadian work with closed stands raised a number of questions. How widely distributed are N deficiencies in soils of eastern Canada, and to what extent can growth of pulpwood stands be improved by addition of fertilizer? Are other nutrients also deficient? Does N interact with other nutrients to improve the efficiency of fertilizer treatments?

Some answers to these questions are found in the early results of field experiments established by the University of New Brunswick in cooperation with the Canadian Forestry Service and industries.

In each of these experiments N was applied at the rate of 150 pounds per acre as urea, P at the rate of 100 pounds per acre as triple superphosphate, and K at the same rate as P as sulfate of potash. Applications were made in factorial combination, giving rise to the following treatment combinations: (1) control, (2) K, (3) P, (4) P-K, (5) N, (6) N-K, (7) N-P, and (8) N-P-K.

Fertilizer additions were made to 1/10-acre plots. All treatment combinations were replicated five times in randomized blocks. In each 1/10-acre plot a 1/15-acre plot was concentrically located. Within this smaller plot five trees of the dominant and codominant portion of the stand were selected for installation of aluminum tape dendrometers (*Liming* 1957). The tapes were read at the beginning and/or end of each growing season.

Three of these experiments (Piskehegan, Bathurst, and Canaan) were installed in 55- to 65-year-old black spruce stands of the central and eastern lowland portion of New Brunswick. This area is underlain by red and grey sand and siltstone of Pennsylvanian and Mississippian age. Soils have developed in till,

SOIL, COVER TYPE, AND FERTILIZATION RESPONSE

It was early recognized that N mobility is greatly reduced where forest litter accumulates to form thick surface layers of decay-resistant debris (Hesselman 1917). Since then, the problem of raw humus formation has been dealt with by numerous scientists and practicing foresters. Notable are the reports of Rommel (1935), Wittich (1952), and Handley (1954).

which is derived mainly from the underlying bedrock. These soils are characterized by unusually low Ca saturation of the exchange complex and high acidity. A dominating feature is compaction, which starts in the transitional B horizon and increases with depth. This condition impedes drainage to various degrees and restricts rooting to the very surface layers of the soil.

The three stands responded in a similar way to fertilizer treatments (fig. 1). Trees showed small increases in basal-area growth with addition of K, and somewhat larger increases with addition of P. Of the one-element treatments, addition of N was most efficient. Maximum growth responses were obtained with combined N and P additions. Application of all three elements was less effective than N-P treatment. Response analysis of two-element treatments showed large and statistically highly significant N main effects (table 2). Main effects of P comprised from 30 to 50 percent of the total response to the N-P treatment. Potassium main effects were smallest and non-significant. Nitrogen and K, and P

and K, interacted negatively in all cases. A notable positive N-P interaction was observed in the Bathurst experiment.

Two additional experiments were established in the central elevated portion of New Brunswick, (at Nashwaak and Sevogle) where intrusive igneous rocks of variable base content have uplifted paleozoic slate, greywacke, and argillite formations. The soils have developed in a mineralogically richer till than that of the lowland region. Compaction is present in the substratum, but it is less pronounced than in soils of the lowland region; and rooting in the mineral soil is more intensive than in soils of the lowland regions. The forest cover of the experimental sites consisted of mixed stands of red spruce and balsam fir with an average age of approximately 55 years.

Red spruce, the dominant species at the Nashwaak site, also showed maximum response to N-P treatment even though the two elements showed a small negative statistical interaction (fig. 2). N and K did not interact negatively as observed at the black spruce sites. The re-

Figure 1.—Response of maturing black spruce to N, P, and K fertilization at various locations in New Brunswick. Black portions of bars represent growth supported by residual fertility, and light portions represent extra growth due to fertilization.

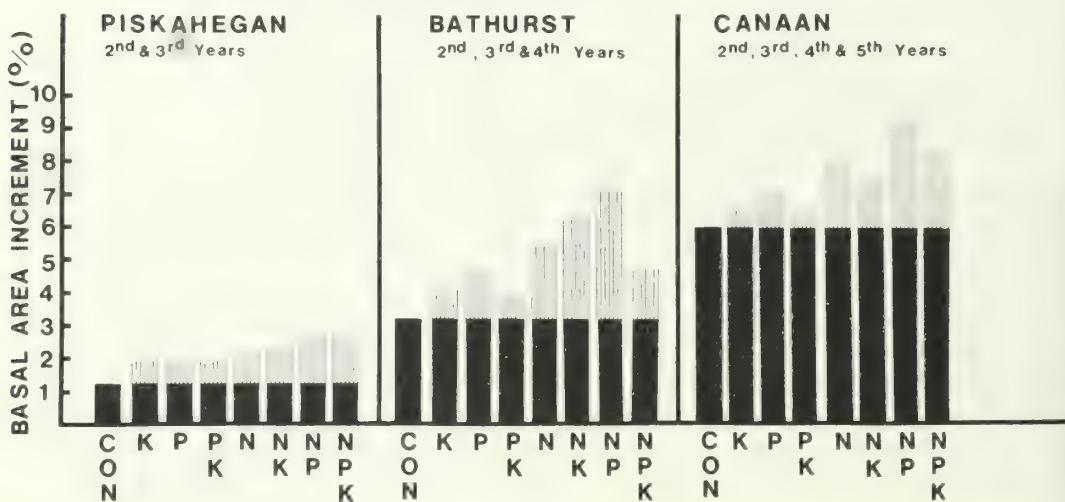


Table 2.—Effect of N, P, and K treatments on growth of maturing conifer stands in New Brunswick

[Growth periods are the same as shown in Figures 1, 2 and 3.]

Treatment	Percent basal-area increment of dendrometer trees						Total response	
	Main effects			Interactions				
	N	P	K	NP	NK	PK		
PISKAHEGAN								
N-P	+0.92	+0.76	—	-0.21	—	—	+1.47	
N-K	+0.92	—	+0.69	—	-0.56	—	+1.05	
P-K	—	+0.76	+0.69	—	—	-0.75	+0.70	
BATHURST								
N-P	+2.20	+1.21	—	+0.36	—	—	+3.77	
N-K	—	+1.21	+0.79	—	-0.10	—	+2.89	
P-K	+2.20	—	+0.79	—	—	-1.33	+0.67	
CANAAN								
N-P	+2.02	+1.05	—	+0.05	—	—	+3.12	
N-K	+2.02	—	+0.46	—	-1.41	—	+1.07	
P-K	—	+1.05	+0.46	—	—	-1.00	+0.51	
NASHWAAK								
N-P	+1.33	+0.96	—	-0.25	—	—	+2.04	
N-K	+1.33	—	+0.49	—	+0.05	—	+1.87	
P-K	—	+0.96	+0.49	—	—	-1.09	+0.36	
SEVOGLE								
N-P	+1.19	+0.16	—	+0.23	—	—	+1.58	
N-K	+1.19	—	-0.06	—	+1.03	—	+2.16	
P-K	—	+0.16	-0.06	—	—	+0.48	+0.58	
GREEN RIVER								
N-P	-0.40	-0.14	—	+1.34	—	—	+0.80	
N-K	-0.40	—	+0.24	—	+1.78	—	+1.62	
P-K	—	-0.14	+0.24	—	—	+0.94	+1.04	

sponse to combined N-K treatment was nearly as great as the response to N-P treatment. K applied in addition to N and P did not yield further growth improvement during the first four growing seasons since addition of fertilizer.

Balsam fir in mixture with red spruce at the Sevogle site responded to N, and to K when applied in combination with N (fig. 2). In contrast to previous observation, this experiment showed a large positive N-K interaction and a notable positive P-K interaction.

A sixth experiment was established on the northwestern plateau of New Brunswick. The soil there developed in till derived from slates, argillites, and limestone formations. Although soils are shallow, the bedrock with its vertical cleav-

ages permits deep rooting. The forest cover is nearly pure balsam fir, approximately 50 years old.

The fertilization response pattern of balsam fir in the pure stand at the Green River site was in sharp contrast with the observed responses of the black spruce stands (fig. 3). Growth was slightly depressed on N- and P-treated plots, but somewhat improved on K-treated plots. N and K fertilizer interacted strongly to yield a notable growth response. Positive interactions were also recorded for N and P and for P and K.

Periodic growth as detected by aluminum tape dendrometers, and foliar nutrient levels determined in taped trees, revealed relationships that seem to agree with fertilization-response patterns.

Figure 2.—Response of mixed spruce and balsam fir stands to N, P, and K at different locations in New Brunswick. Black portions of bars represent growth supported by residual fertility, and light portions represent extra growth due to fertilization.

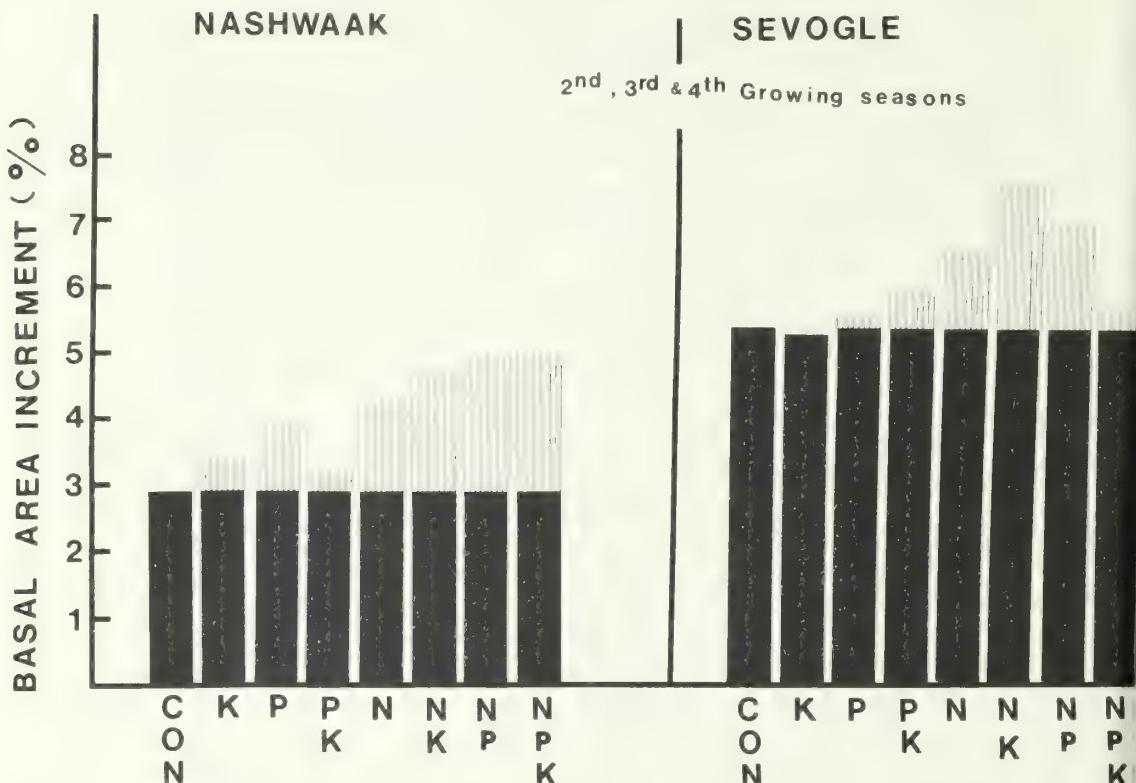
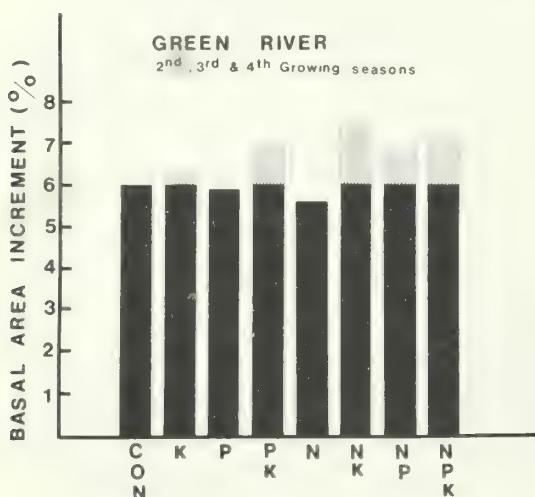


Figure 3.—Response of balsam fir to N, P, and K in the Northwestern Plateau Region of New Brunswick. Black portions of bars represent growth supported by residual fertility, and light portions represent extra growth due to fertilization.



Significant correlation coefficients were obtained for the relationship between foliar N in current-year needles and basal-area growth of all experimental stands except the Green River balsam fir, which did not show a response to N (table 3). No correlation could be shown for foliar P and basal-area growth, probably because of luxurious consumption of P at low N supply.

Foliar K showed negative, non-significant correlation coefficients with growth in black spruce and positive correlation coefficients with growth in balsam fir. Although small, the correlation coefficients for foliar K and growth of balsam fir were significant at the 5-percent level. The ratio of foliar K to foliar N was negatively correlated with growth in the black spruce stands. Correlation coefficients were significant at the 1-percent

Table 3.—Interrelationship between foliar nutrient concentrations determined after completion of the first growing season following fertilizer application and average basal-area increment of dendrometer trees in subsequent years

Experiment	Correlation Coefficients					
	N	P	K	Ca	Mg	K/N
Bathurst	+0.52**	+0.14	-0.19	-0.20	-0.14	-0.48**
Canaan	+0.54**	+0.14	-0.18	+0.49**	+0.21	-0.48**
Piskahegan	+0.40*	-0.04	+0.03	+0.01	+0.19	-0.24
Nashwaak	+0.46**	-0.08	+0.12	n.d.	n.d.	-0.24
Sevogle	+0.53**	+0.14	+0.32*	+0.05	-0.17	+0.02
Green River	+0.22	+0.24	+0.33*	-0.06	-0.40*	+0.14

level. In the Green River experiment, however, the correlation coefficient between the same ratio of foliar nutrient contents and growth was positive.

A fairly close positive relationship was observed for foliar Ca and growth on the Canaan plots and a negative relationship for foliar Mg content and growth on the Green River plots. This observation may be explained by antagonistic relations between K and the divalent ions.

The observed differences in fertilization response patterns may be attributed at least in part to variable fertility of experimental soils.

The native fertility of the soils on the experimental sites has been studied to some extent. The N-releasing properties of forest floor and B-horizon samples

were determined in incubation studies (*King 1972*), and contents of mineral N in forest floor and B-horizon samples after 32 days of incubation at 20°C. are reported as mineralization indices (table 4). Mineralization indices were lowest for black spruce sites, which showed high responses to N addition, and highest for the Green River balsam fir site at which the same treatment yielded no response. Mineralization indices of the B-horizon showed a narrow range and were less consistent with responses than indices of the L-F-H layers.

P was extracted from soil and forest floor by shaking suspensions for 24 hours with anion exchange resin. Far greater quantities of P were extracted from L-F-H layers than from B-horizon samples.

Table 4.—N and P availability in forest floor and B horizon, and response of conifer stands to fertilizer treatment at various locations in New Brunswick

Experiment	Forest Cover	Nitrogen			Phosphorus		
		Mineralization Index ^a		Response	Resin-extract ^b		Response
		LFH	B		LFH	B	
Piskahegan	Black spruce	11	29	Percent	40	2.8	+59
Bathurst	Black spruce	19	21	+68	122	4.5	+37
Canaan	Black spruce	22	107	+36	93	1.9	+17
Nashwaak	Red spruce, Balsam fir	158	51	+41	101	2.5	+30
Sevogle	Balsam fir, Red spruce	50	60	+22	296	5.5	+3
Green River	Balsam fir	278	95	-7	245	5.0	-2

^aMineralization index is the content of mineral N, in p.p.m. after 32 days of incubation at 20° C.

^bResin extractable P is given in p.p.m.

Figure 4.—Relationship between growth of black spruce to age 40 and rooting-space index, which is determined by depth to compacted layer (cm.) plus the reciprocal of the bulk density (g./cm.³) of the compacted layer.

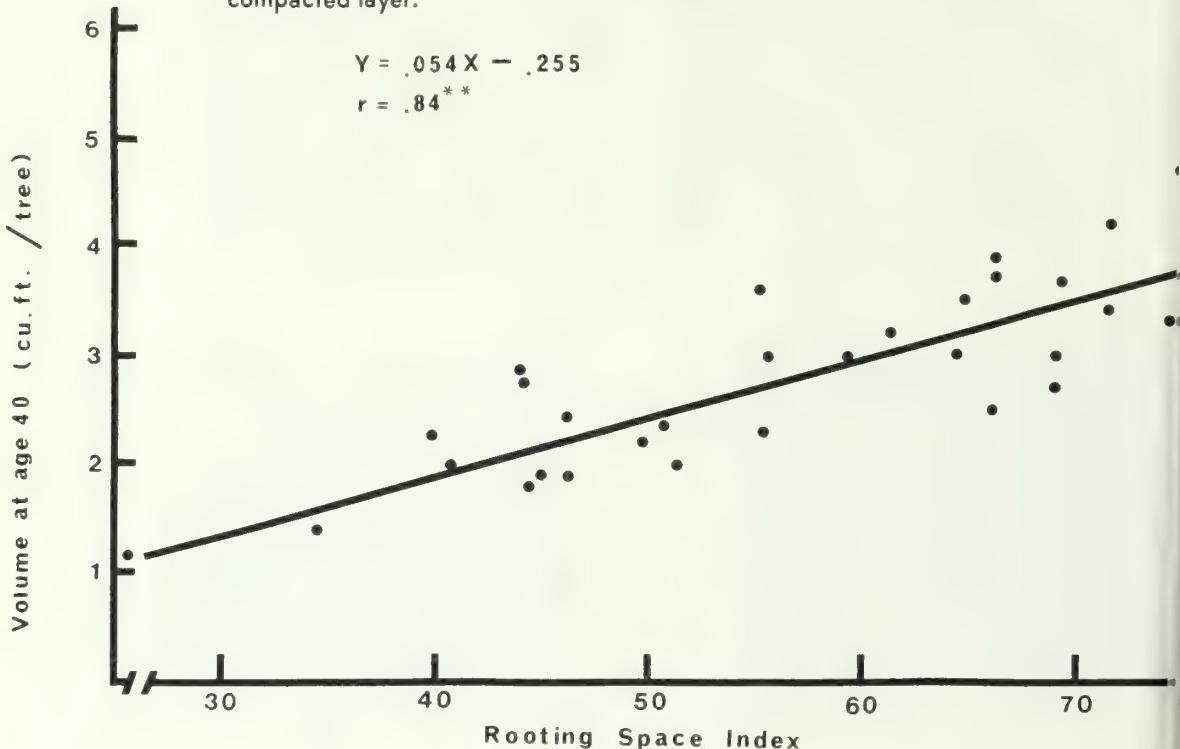
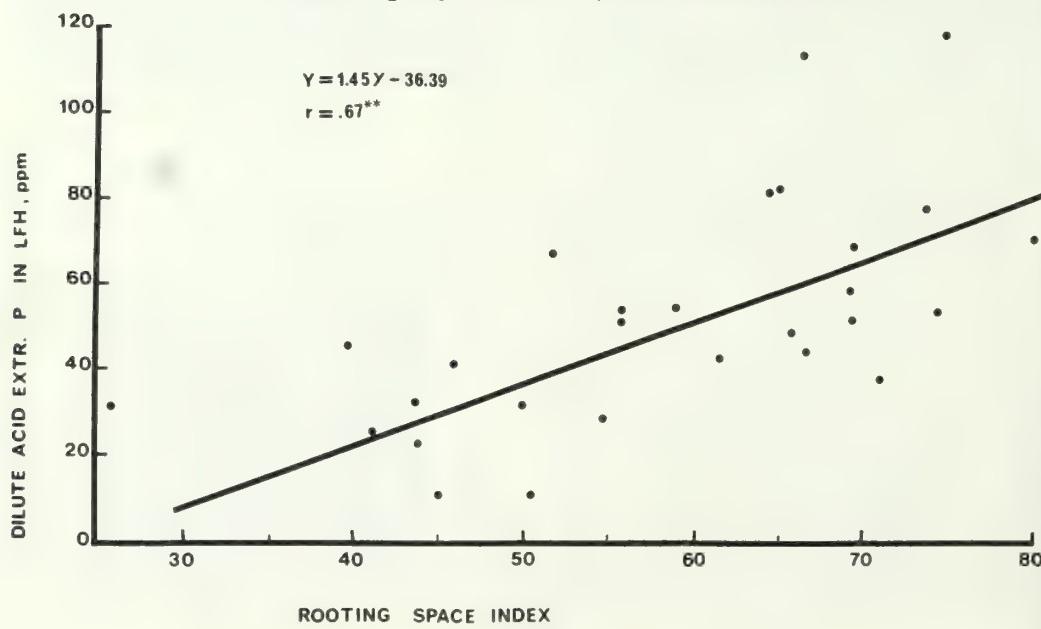


Figure 5.—Relationship between P content in the forest floor extractable with 0.002N H₂SO₄ buffered at pH3 and rooting-space index.



Lowest concentration and highest growth responses to P addition were found at the Piskahegan black spruce site; highest concentrations and very small or no growth responses were found at the two balsam fir sites (table 4).

Additional work with black spruce in the central lowland region of New Brunswick has indicated that an interrelationship may exist between soil physical properties, soil fertility, and tree growth (*MacFarland and Krause 1972*). A very close correlation could be shown between volume growth to age 40 years and a rooting-space index, which is given by the depth in cm. to the compacted layer plus the reciprocal of the bulk density (g.cm.⁻³) of the compacted layer (fig. 4). The rooting-space index, in turn, was well correlated with dilute-acid extractable P in the forest floor (fig. 5).

K relationships of the experimental soil have not been studied in detail, and it is difficult to explain the different behaviour of stands to K addition. Green River balsam fir tended to absorb larger quantities of Ca and Mg than spruce in the lowland regions. It is conceivable that the Green River soil contained higher Ca concentrations than the lowland soils. In agreement with the concept of K intensity in soil (*Beckett 1964*), high contents of divalent ions may lower K uptake even though the concentration of soluble and exchangeable K may remain unchanged.

Fornes *et al.* (1970) observed differences in the response of adjacent red pine and Norway spruce plantations to K fertilization of a sandy soil. They attributed this variable behaviour of the two species to differences in their mineral requirements. It is possible that such species differences also explain, in part, the variation in response patterns of our experiments.

Data gained from the six experiments are not sufficient to derive quantitative relationships between soil properties and fertilizer response nor to prepare treat-

ment recommendations that guarantee maximum growth increases in the various regions of the province. However, this information has provided the basis for continued study. Using single-tree plots we are now engaged in determining response surfaces, emphasizing N and P at lowland black spruce sites and N and K at fir and spruce-fir sites in the elevated regions of New Brunswick.

SOME ECONOMIC ASPECTS OF FOREST FERTILIZATION IN EASTERN CANADA

A realistic example showing benefits to be derived from forest fertilization has been given recently by Pritchett and Hanna (1969). A slash pine plantation producing 30 cords per acre within a 25-year rotation on poorly drained sandy soil in the southeastern region of the United States may yield an additional 6 cords per acre with 200 pounds of concentrated superphosphate applied per acre after planting. With a stumpage price of \$8 per cord and fertilization cost of \$10 per acre, the return on the fertilizer investment is 6.5 percent, compounded annually for 25 years.

Although fertilization is being carried out on an operational scale within the latitudes of the northern forest, the economic aspects of such treatments have not been tested extensively. Sufficient information seems to be available for estimating the cost of fertilizer treatment (*Anderson 1969*), but biological information does not appear to be adequate for predicting growth responses reliably. Schweitzer (1971) was uncertain whether the available experimental evidence is adequate for justifying the large investments for fertilization in the Pacific Northwest of the United States.

Swan (1970b) dealt with the economic aspects of forest fertilization in Canada in a paper presented to the Canadian

Council of Resource Ministers. He pointed out that very few response data from eastern Canadian forest fertilization trials are available; but he indicated that, based chiefly on Swedish experience, the cost of fertilizer-grown wood, on the stump, could range from less than \$5 per cunit, in favourable circumstances, to several times this in an unfavourable situation. He stressed that it is the cost of wood delivered to the mill that is of key importance to the wood-using industries, and that the main economic justification for forest fertilization under conditions where the allowable cut exceeds the actual cut is its potential for reducing hauling cost by increasing the productivity of sites relatively close to the mill.

Swan indicated the need for cost-sharing agreements between the landlord (the province) and the tenant (the limit holder) so as to provide an incentive to the latter to undertake forest-fertilization practices; alternatively, the province could waive stumpage charge on fertilizer-grown wood. He added that, with the continually diminishing reserves of readily accessible virgin forest and the steadily increasing demand for wood, there is only one way for the value of wood to go—up. As the value of wood rises, so does the incentive to increase yields, especially in stands close to the industries. He concluded that fertilizers would therefore seem to have an important role to play in the more intensive forestry of tomorrow.

The variability in stocking, yield, and composition of naturally regenerated stands may prove to be a difficulty in forest fertilization on operational scale in eastern Canada. Care must be taken when the results from small experimental plots are used to predict response in large-scale fertilization. Experimental plots are usually chosen in uniformly stocked portions of the stand. Growth rates and fertilization response determined on such plots would tend to be

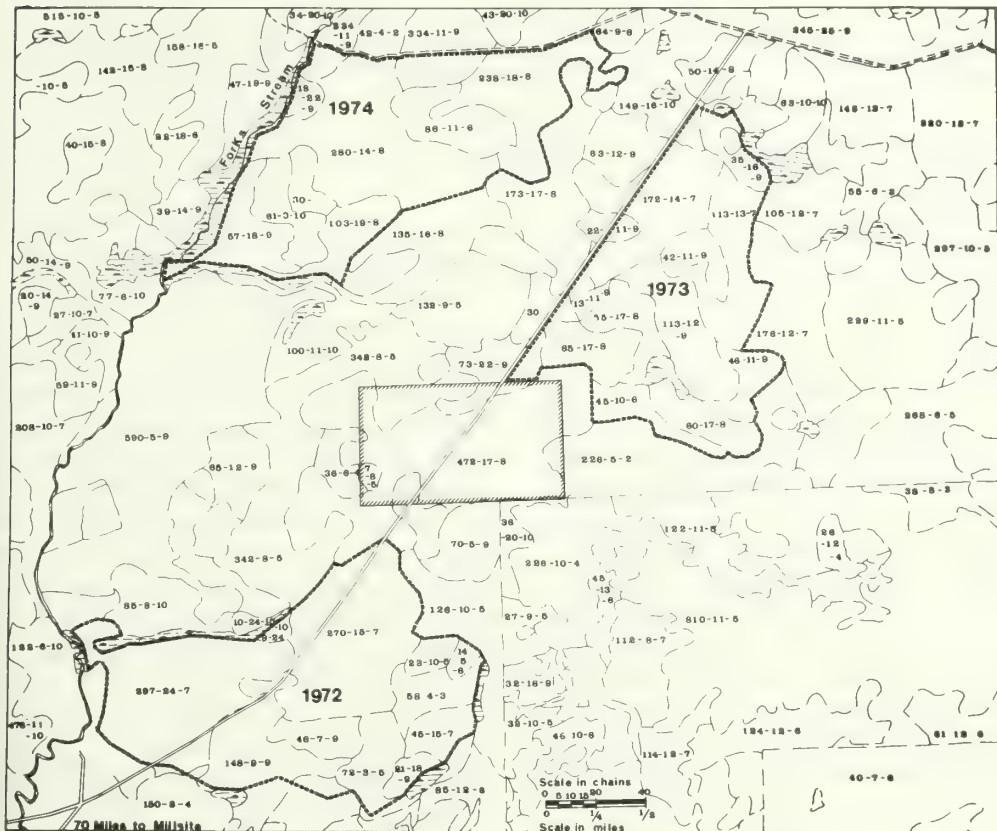
higher than the average growth and response on a large block of forest land that has been fertilized from the air.

Forest conditions in the eastern lowland portion of New Brunswick are exemplified in a type map (fig. 6), prepared by one of the forest industries of the province and slightly modified for the purpose of this discussion. Within the relatively small area marked for cutting in 1972, the variability of stands is such that uniform treatment would not have been justifiable had the company decided to fertilize this area 8 to 10 years before cutting. The large 297-acre block with 24 cunits of harvestable pulpwood is probably over-mature, and present losses through wind breakage may be larger than potential gains from fertilizer treatment. Other smaller blocks support stands with a softwood volume too low to be considered for fertilizer treatment. The only portion that could have been recommended for fertilizer treatment is the irregularly shaped 270-acre block that now supports an average of 15 cunits of merchantable softwood per acre.

Assuming that the company operating in this area wished to improve future stand yield, it could select for fertilization an area such as the rectangular 400-acre block immediately above the 1972 cut. This block comprises a large portion of a 472-acre stand with 80 percent black spruce and balsam fir and a present merchantable volume of 17 cunits per acre. Based on experience gained with similar stands and soil, application of urea at the rate of 400 pounds per acre and of triple superphosphate at the rate of 200 pounds per acre may be recommended.

This treatment, if made in 1973, would be expected to improve the yield by a minimum of 2 cunits per acre over the next 10-year period. Merchantable volume at the time of harvesting would be expected to be 24 cunits per acre or larger instead of 22 cunits per acre. Assuming that experience gained in the northwestern and southeastern regions of

Figure 6.—Type map showing stand distribution and yield in a black spruce area of central New Brunswick. Types are delineated by thin lines and identified by sets of figures giving acreage, yield (cunits/acre) of spruce and balsam fir wood, and proportion (tenths) of total volume consisting of spruce and balsam fir. Areas delineated by heavy broken lines are marked for cutting in year indicated. Map reproduced by courtesy of MacMillan and Rothesay, Ltd., Saint John, N. B.



the United States is applicable to conditions in eastern Canada, the cost of fertilizer treatment is estimated at \$26.80 per acre. This includes purchase in bulk of urea at \$65 per ton, triple superphosphate at \$60 per ton, hauling and fertilizer storage at \$6 per ton, and helicopter application at \$20 per ton.

Stumpage prices of pulpwood are very low in eastern Canada, and the value of 2 cunits of fertilizer-grown wood would be far too small to pay the cost of fertilization. However, economists, management,

and industrial foresters agree that benefits from fertilization are not limited to the value of the additional volume of wood. Savings may be realized in harvesting and transportation costs.

Table 5 shows the estimated cost of wood at mill site from the 400-acre block marked in figure 6. The given example is hypothetical, as none of the amounts listed represents actual costs incurred by any one company. However, the given per-cunit amounts are believed to be representative for New Brunswick conditions (per-

Table 5.—Hypothetical example of cost of wood at mill site from a 400-acre block located 70 miles from the mill and would yield 8,800 cunits without treatment and 9,600 cunits with fertilizer addition 10 years before cutting

Item	Without fertilization		With fertilization	
	Total harvest		Total harvest	
	Dollars	Cunits	Dollars	Cunits
Felling & processing	83,600.00	9.50	83,600.00	8.70
Off-road transport	30,800.00	3.50	33,600.00	3.50
Delivery	79,200.00	9.00	86,400.00	9.00
Stand establishment & protection	26,400.00	3.00	26,400.00	2.75
Support functions	26,400.00	3.00	26,400.00	2.75
Stumpage	39,600.00	4.50	39,600.00	4.13
Service functions	13,200.00	1.50	13,632.00	1.42
Treatment:				
Fertilizer & application	—	—	12,640.00	1.32
Interest (2.9%)	—	—	4,128.00	0.43
Total	299,200.00	34.00	326,400.00	34.00

sonal communication from T. C. Bjerke-lund and W. G. Paterson). It is further assumed that harvesting was mechanized, with equipment of the Koehring-Waterous type. With this system, productivity is determined by length of tree bole to be processed per unit volume of wood harvested. Since the effect of fertilization is found in increased diameter growth over the entire length of the tree, and since it does not noticeably affect the height of the tree, the cost of felling and processing of the additional fertilizer-grown wood is negligible. The cost of felling and processing of the total amount of wood from the 400-acre block would then remain unchanged, and the cost per cunit of wood could be noticeably reduced with fertilization.

The amount allotted per cunit for stand establishment and protection is reduced with fertilization because the area involved remains unchanged. Similarly, savings are materialized on a per-cunit basis in support and service functions, which include road construction and maintenance, buildings, transportation of men, goods and materials, accounting, etc. If fertilization is carried out by a company on leased land, it would be reasonable to expect that stumpage pay-

ments to the landowner for fertilizer-grown wood are waived. This would lead to a reduction in per-cunit stumpage price for wood from the fertilized area. To the cost of wood from fertilized soil must be added the cost of fertilization, which in the given example amounts to \$1.32 per cunit. If the total cost of 1 cunit of wood harvested after fertilization is allowed to be as high, but not to exceed the cost of 1 cunit of wood harvested without fertilization, the investment would bear interest at 2.9 percent, compounded annually over 10 years.

The individual items contributing to the total cost of wood with and without fertilization must be expected to vary widely, depending on woodland conditions and efficiency of company operations. The benefits to be derived from fertilizer treatment must therefore be evaluated carefully in each case. The hypothetical interest rate of 2.9 percent may be substantially higher in some cases and lower in others. Whether or not a company would wish to fertilize under condition of the above example would depend on several factors, foremost wood supply, market stability, and labour relationships.

CONCLUSIONS

Forest growth in eastern Canada is commonly limited by nutrient shortage. Nitrogen deficiencies seem to be most frequent. Probably as a result of low temperatures and reduced biological activity in soil, deficiencies usually develop after stand closure. Stands are characterized by low foliar N contents and very low concentrations of mineral N in the forest floor, a major feeding zone. These stands respond to N additions with increased volume growth.

Urea appears to be a suitable N carrier, although care must be taken in experimental work because control areas may be contaminated by absorption of volatilized NH₃. Response to addition of P may be expected under conditions of impeded drainage and low concentrations of readily available P in the forest floor. Fertilizer P may act independently or may interact positively with N.

On well and excessively drained sites with deep rooting, K deficiency may occur. As in the case of P, fertilizer K may act independently of or interact positively with N to improve growth of closed stands and young plantations.

Fertilizer use on an operational basis would require careful study of soil and stand conditions before treatment. A single application of N may not always produce the desired results. In some instances, such a treatment may remain entirely ineffective. Maximum returns from fertilization can be expected only if such treatments establish and maintain nutritional balance.

Fertilizer use may be attractive to industries whose wood supplies are diminishing and whose operations are mechanized. It may not be profitable for an owner of woodlands to fertilize unless he harvests and delivers wood to the processing centres. Stumpage prices of wood are usually too low in eastern Canada for recovery of investment in fertilization.

Major returns are in reduction of harvesting and delivery costs.

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FOREST FERTILIZATION IN THE EASTERN UNITED STATES: CONIFERS

by L. O. SAFFORD, *Research Forester, USDA
Forest Service, Northeastern Forest Experiment
Station, Forestry Science Laboratory, Durham, N. H.*

ABSTRACT. Past and current forest-fertilization experiments have demonstrated that northeastern conifers respond favorably to nutrient supplements when deficiency conditions exist. No universal combination of nutrients or application rate has given response in all situations. Applications of fertilizer to forests are advocated only as a part of intensive silvicultural practice in situations where silvicultural and management objectives are well defined. Wide-scale extensive fertilizer applications in unmanaged natural forest stands are rejected because of high economic and possible environmental risks.

I APPROACH this discussion from the viewpoint of the forest-land manager looking at fertilization as a potential management tool, rather than as a forest scientist looking for details of research studies. I define forest fertilization as the addition of an inorganic or organic substance to stands of forest trees for the purpose of stimulating tree vigor and growth. With this definition in mind, I address my remarks to the following question:

What is the status of forest fertilization of conifers as a silvicultural tool in the Northeast today?

I will deal in general terms with research results of past studies and briefly outline present forest fertilization research, particularly field studies. And finally, I will give my views of forest fertili-

zation as a forest management tool and try to point out some of the questions that must be answered in the future.

PAST RESEARCH

In searching the literature of field trials of fertilizer with northeastern conifers, I found that the work in New York has been concerned mainly with K deficiency and that studies at The Pennsylvania State University have been concerned mainly with treatment of sewage effluent.

The main conifers studied have been white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), the spruces (*Picea glauca* (Moench) Voss, *P. rubens* Sarg., *P. mariana* (Mill.) B. S. P., and *P. abies* (L.) Karst.) and balsam fir (*Abies balsa-*

mea (L.) Mill.). Mineral nutrition of other important northern conifers—hemlock (*Tsuga canadensis* (L.) Carr.), tamarack (*Larix laricina* (Du Roi) K. Koch), northern white-cedar (*Thuja occidentalis* L.), eastern redcedar (*Juniperus virginiana* L.), and pitch pine (*Pinus rigida* Mill.)—is known only through a few studies of foliage nutrient content and other basic aspects.

The northeastern region has, in comparison with other regions of this country, eastern Canada, and Europe, a relatively low frequency of published research findings (table 1) on the applied or practical aspects of fertilization of conifers as a silvicultural tool.

As early as 1927, greenhouse research was done on the nutrient requirements of black spruce, an economically important northeastern conifer (Herbert 1927). Beneficial effects of organic mulches (Lunt 1951a, 1951b) and inorganic salts (Heiberg and White 1951) and municipal waste water (Sagmuller and Sopper 1962) have all been demonstrated in field applications here in the Northeast. Results of field studies have not always been consistent: identical treatments with the same species in different locations have not always given the same response. This emphasizes the importance of soil type and other site factors in response to fertilizer.

The most clearly defined and best understood nutrient problem in the region is that of K deficiency on coarse-textured

outwash soils of the Northeast (Stone and Leaf 1967). The work of the late S. O. Heiberg and his associates is an outstanding example of specifically defining a problem and demonstrating a solution. This work showed that a single application of K fertilizer to pine or spruce corrects a limiting growth factor, and a sustained growth response is obtained (Heiberg and White 1951, Fornes et al. 1970). This K deficiency is known to be a wide-ranging problem in Quebec (Lafond 1958, Stone and Leaf 1967) and Maine (Stratton et al. 1968).

A pilot-plant-scale application of K fertilizer from aircraft reported by White (1956) demonstrated the feasibility of large-scale practical applications. Summaries of the research and basic recommendations for treatment of K deficiencies and a similar problem with Mg elucidated by Stone (1953) were published in a practical version (Heiberg et al. 1954).

Yet, to the best of my knowledge, in the almost 20 years since this work was done, forest managers have not made use of these research findings by seeking out and treating the conifer plantations and natural stands that occur on the K-deficient sandy soils of the Northeast.

PRESENT RESEARCH

Basic research on nutrient requirements, uptake, utilization, and other fundamental ecological and physiological aspects of forest-tree nutrition is in progress at many of the major universities,

Table 1.—Numbers of papers about forest fertilization of conifers abstracted in Forestry Abstracts section 237: Silviculture, Amelioration of Forest Sites 1957-1971

Date	Location				
	Europe	Eastern Canada	United States		
			Northwest	Southeast	Northeast
1957-61	102	1	3	11	4
1962-66	81	6	4	9	4
1967-71	163	13	10	25	12
Total	346	20	17	45	20

agricultural experiment stations, and by the USDA Forest Service throughout the northeastern region.

Forest industry is currently sponsoring a fertilizer field trial in the spruce-fir forest type in cooperation with the University of Maine. This study is a factorial design with N, P, and K, and some additional N level treatments. Three study areas are located in eastern, north-central, and western Maine. The design and objectives of this work are similar to the Canadian comprehensive study described by Professor Krause. Results to date indicate a diameter growth response to the complete N-P-K treatment in the eastern Maine location but not in the other two. Lack of rainfall and consequently low soil moisture are suggested as possible reasons for lack of response (*Schomaker* 1972) in these areas.

Maine forest industries are also conducting some fertilizer experiments of their own. Scott Paper Company has fertilized about 300 acres in mature spruce-fir stands and regenerated spruce-fir cut-over areas. Ammonium nitrate at rates of 100, 150, or 200 pounds of N per acre was applied from a helicopter. Height growth of young spruce and fir in the regenerating stands increased 10 to 45 percent above that on unfertilized areas. Data from mature stands have not been analyzed.

The Dead River Company has fertilized 325 acres with aerial applications of urea in mature and second-growth stands of primary softwood (spruce-fir-hemlock) species, mixed softwood-hardwood stands, and hardwood (birch-beech-maple) stands. Rates of application varied from 50 to 150 pounds of N per acre. Preliminary growth measurements indicate small but definite trends of increased growth of fertilized plots over controls. The Dead River Company has also started a more closely controlled

study involving ground application of N, P, K, and minor elements in various combinations and amounts in a second-growth softwood stand.

Several other companies have less extensive but well-designed ground-applied fertilizer studies in progress. Oxford Paper Co. has applied N, P, K, and lime to various species and age classes. Great Northern Paper Co. has applied N, P, K, and lime to mature and regenerating softwood stands. Donworth Timberlands has tried trenching for drainage, combined with lime and N-P-K fertilizer, for regenerating black spruce stands.

There probably are other fertilizer trials that I do not know about elsewhere in the northeastern region. However, I know that forest managers are serious enough about exploring fertilization as a management tool to invest company funds in research projects. In most cases this work has been initiated on the recommendation of company executives. These people have seen fertilizer work in Europe or other regions of this country—sometimes within their own company—and they want to get information applicable to their northeastern lands.

The most immediate benefit to come from these first studies, particularly the larger scale aerial applications, is information about logistics of fertilization. The projects have been large enough to produce cost figures and data on some of the personnel, equipment, distribution-control, and sampling problems that will pertain to operational fertilization projects. None of the operational aspects were particularly discouraging, including the modest costs of \$20 to \$30 per acre.

Thus past basic studies and current operational-scale applications have demonstrated that fertilization can be a useful management tool here in the Northeast from both biological and management points of view.

FOREST FERTILIZATION CRITERIA

I do not believe that forest fertilization as a silvicultural practice can be applied on the same extensive basis as "forestry" or "forest management" is applied in the Northeast today. Fertilization is not a magic cure-all that can, all by itself, solve the woodland manager's problems of sustaining or increasing a wood supply from a fixed land base. Fertilization is but one input in intensive silviculture. It has a place in forest management along with protection, genetic selection, and the all-important control over species composition and stand density. But extensive and indiscriminate aerial applications of one kind of fertilizer at a fixed rate to vast areas of forest land could be extremely wasteful from an economic point of view and potentially hazardous to the environment.

We cannot simply accept forest fertilization as a good thing and set about fertilizing the forest. We must make certain that the potential productivity of the stand is obtained through the fundamental silvicultural inputs, particularly control of species composition and stocking levels. We must fertilize not the forest, but a crop. Specific selected trees must be supplied with required nutrients in such a manner that a specific growth-limiting factor is eliminated.

This implies an ability to diagnose nutrient deficiency problems in a specific way and to apply treatments that will solve the problem. To do this, we must be in the business of growing a crop. We must know what the crop is, and what our specific management objectives are.

These objectives cannot be as loose and extensively defined as our management of today's natural stands, whether

of mature, semi-mature, or regeneration age classes. We need specific answers for our region to the age-old inquiries: Where?, What?, When?, and How? The *where* entails defining the species and soil-site situation that can be improved by additional nutrients. *What* asks for the nutrient element or element combinations and what source compound is required to best supply the deficiency. The *when* concerns stage within the rotation and seasonal timing of applications. The *how* covers methods of application, both mechanical distribution and method of placement.

RESEARCH VERSUS APPLICATION

We cannot afford, nor is it necessary to wait for research to answer each of the above questions with significantly demonstrated statistically proven answers. There is not enough time. I believe we are well enough versed in the art of forest fertilization to begin using it now as a silvicultural tool. The first applications should be well enough defined that anticipated benefits will economically justify the treatments applied. The well-defined potassium problem discussed earlier is an excellent example.

Feedback from success or failure of these practical ventures will gradually build up a technology of treatments that work—and sift out specific applications that do not work. From this basic backlog of experience in *how to* and *how not to* fertilize, research can define and conduct studies to answer some of the *why's*. Interaction between this applied experience and the research answers will generate a strong foundation for intensive silvicultural practice—including forest fertilization.

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FOREST FERTILIZATION IN THE EASTERN UNITED STATES: HARDWOODS

by L. R. AUCHMOODY and S. M. FILIP, Research Foresters, USDA Forest Service, Northeastern Forest Experiment Station, Forestry Sciences Laboratories, Warren, Pa., and Durham, N. H., respectively.

ABSTRACT. Attempts to improve growth rates of eastern hardwoods by fertilization date back to the early 1930's. Many reports have shown that many species growing on many different sites are responsive to various fertilizer additives. Unfortunately, however, only a small portion of this information is applicable to eastern hardwood forests. Much more research is needed to determine how widespread nutrient deficiencies may be in the northeast and to answer practical questions of how much, when, and where fertilizer amendments are necessary.

INTEREST in forest fertilization to increase production of wood fiber has escalated in the past decade. And for good reason. Well-designed field tests with a number of species have demonstrated favorable growth response—in some cases dramatic response—to fertilization. These results—and progress in fertilization research in general—have been summarized in a number of excellent reviews (*White and Leaf 1957, Duke University 1959, Arneman 1960, Walker and Beecher 1963, Tamm 1964, Mustoja and Leaf 1965, Arsmson 1967, Bengtson 1968, Baule and Fricker 1970*). Unfortunately, relatively little of this past work applies directly to hardwoods in the eastern United States.

In this paper we have attempted to

provide an up-to-date progress report on fertilization of eastern hardwoods for increased fiber production.

ACCOMPLISHMENTS

The first experiments involving field fertilization to improve growth rates of eastern hardwoods date back to the early 1930's (table 1). Probably the first work was started by Wyman (1936) with young pin oak (*Quercus palustris* Muench.) near Ithaca, N.Y., in 1930–31. This test, conducted under lawn conditions, showed that diameter growth was increased for two to three seasons by a single application of N. In 1934, tests were made on mature American elm (*Ulmus americana* L.) and in

Table 1.—Summary of published hardwood field fertilization tests

Major species	Tree size	Nutrients tested	Location	Reference
American elm	Standards	N	New York	Pridham (1939)
Black walnut	Seedlings	N,P,K	Michigan	Schneider et al. (1970)
Cottonwood	Cuttings	N	Tennessee	Curlin (1967)
Dogwood	Understory	N,P,K; lime	Tennessee	Curlin (1962)
Green ash, American elm, red oak, black locust	Seedlings	N,P,K	Iowa	McComb (1949)
Honey locust	Saplings	P,K	Blue Ridge Mts.	Zarger and Lutz (1961)
Hybrid poplar	Cuttings	N,P,K	Quebec	Aird (1956)
Hybrid poplar	Seedlings	N,P,K	Quebec	Aird (1962)
Hybrid poplar	Saplings	N,P,K	Ohio	Aughanbaugh and Mitchell (1963)
Mixed oaks, sugar maple, beech, hickory, black gum, yellow-poplar, basswood, white ash	Standards	N	Southern New York	Mitchell and Chandler (1939)
Mixed oaks, red maple	Standards	N,P	Southern New York	Finn and Tryon (1942)
Mixed oaks	Standards	N,P; lime	Pennsylvania	Ward and Bowersox (1970)
Pin oak	Saplings	N	New York	Wyman (1936)
Pin oak, white ash, honey locust	Saplings	N,P,K; trace elements	Illinois	Himelick et al. (1965)
Red oak	Standards	N	New York	Pridham (1941)
Sugar maple	Standards	N,P,K	Massachusetts	Mader et al. (1969)
Sweetgum, water oak, willow oak	Poles	N,P,K	Louisiana	Broadfoot (1966)
Sweetgum	Poles	N,P,K	Illinois	Gilmore et al. (1971)
Sycamore	Cuttings	N,P,K	Piedmont	Huppuch (1960)
Sycamore	Seedlings	N,P,K	Georgia	Broadfoot and Ike (1968)
Various	Saplings, poles, standards	N,P,K Mg; trace elements	Illinois	Neely et al. (1970)
White ash	Seedlings	N,P,K; lime	Ohio	Cummings (1941)
Yellow-poplar	Seedlings	N,P	Georgia	McAlpine (1959); Ike (1962)
Yellow-poplar	Seedlings	N	Ohio	Chapman (1933)
Yellow-poplar	Poles	N,P,K	Michigan	Finn and White (1966)
Yellow-poplar, mixed oaks, hickory	Various	N,P	Tennessee	Farmer et al. (1970)
Yellow-poplar	Seedlings	N,P	Tennessee	Farmer et al. (1970)
Yellow-poplar	Poles	N,P,K; Ca	Ohio	Vimmerstedt and Osmond (1970)
Yellow-poplar	Seedlings	N,P,K	Mississippi	Blackmon and Broadfoot (1970)

1936-40 on roadside red oak (*Quercus rubra* L.) (Pridham 1939, 1941). In these tests, N fertilization produced a marked response in foliage color, but diameter growth was not substantially increased.

Also in the early 1930's, Chapman (1933) found that yellow-poplar (*Liriodendron tulipifera* L.) responded to ammonium nitrate applied to silt loam soils of Ohio. On acid soils of low fertility, however, applications of N, P, K and dolomitic limestone to white ash (*Fraxinus americana* L.) and yellow-poplar failed to produce a marked growth response (Cummings 1941).

In 1935-37 Mitchell and Chandler (1939) established a series of field plots in southern New York to test the effects of N rates on growth of mixed northern hardwoods. From this work, the first extensive experimentation in forest stands and now a classic, they reported response and "optimum" foliar N concentrations for 11 hardwood species. In a subsequent evaluation, Chandler (1943) noted that response had persisted for 7 years, and at that time fertilized white ash were still growing at twice the rate of unfertilized control trees.

In 1938, Finn and Tryon (1942) began field tests on the Black Rock Forest to compare the effects of leaf mould, N, and P fertilizer additions on growth of mixed oaks and red maple. Best growth was obtained with leaf mould, followed by P, and then N. The increase measured over 3 years amounted to 64, 42, and 23 percent more than growth of controls, respectively.

Beginning in 1939 and continuing through the mid-40's, McComb (1949), in Iowa, conducted extensive fertilization tests with red oak, American elm, green ash (*Fraxinus pennsylvanica* Marsh.), and black locust (*Robinia pseudoacacia* L.). Although many of these tests were run in pots, he also made field experiments showing that N and P deficiencies were factors limiting growth of ash and

red oak on forest soils; that N was more severely limiting than P; and that once the initial N deficiency was overcome, the addition of P was associated with a further growth increase. Black locust showed response to P only, indicating that this leguminous tree was nodulated and fixing its own N.

In the following decade and early 1960's several hardwood fertilization studies dealing almost entirely with planted seedlings on non-forest sites indicated the responsiveness of yellow-poplar, honey locust (*Gleditsia triacanthos* L.), hybrid-poplar (*Populus* cv. Charkowiensis X *P. cv. Caudina*, *P. cv. Generosa*), and sycamore (*Platanus occidentalis* L.) to fertilizer additives (Aird 1956 and 1962, McAlpine 1959, Huppuch 1960, Zarger and Lutz 1961, Ike 1962, Aughabaugh and Mitchell 1963).

And in another study, dogwood (*Cornus florida* L.) showed a marked response to fertilization in tests evaluating N, P, K and dolomitic lime under forest conditions (Curlin 1962). Response, attributed exclusively to N, was greatest during the first season, diminished rapidly thereafter, and was not significant during the third and fourth seasons.

More recently, fertilization trials in established stands have provided useful information about the extent of nutrient deficiencies and the duration and degree of response obtainable. In a slow growing yellow-popular stand in Michigan, N-P-K fertilization increased height growth 100 percent, diameter growth 85 percent, and lasted in some degree for 5 years (Finn and White 1966). In Massachusetts, a threefold increase in diameter growth of declined sugar maple (*Acer saccharum* Marsh.) occurred after a complete N-P-K treatment (Mader et al. 1969).

In mixed upland hardwood stands in the Tennessee Valley, where widespread N and P deficiencies occurred, 5-year basal-area growth was increased approximately 50 percent by N-P fertilization

(Farmer et al. 1970). In Pennsylvania, N and lime applications in a mixed upland oak stand produced a 45-percent increase in volume over a 5-year period (Ward and Bowersox 1970). In southern Illinois, 5-year basal area and height growth of sweetgum (*Liquidambar styraciflua* L.) were increased 60 and 33 percent, respectively, by N fertilization (Gilmore et al. 1971).

In Ohio, the best 2-year volume growth of yellow-poplar was obtained at high rates of N and P in combination with low rates of K (Vimmerstedt and Osmond 1970). In Mississippi, annual N and N-P-K applications produced 65- and 44-percent responsees in diameter and height growth, respectively, in sweetgum, water oak (*Quercus nigra* L.), and willow oak (*Quercus phellos* L.) stands (Broadfoot 1966). Similar responses for other timber species in various sections of the country have also been observed (Blackman and Broadfoot 1970, Broadfoot and Ike 1968, Carter and White 1970, Curlin 1967, Farmer et al 1970, Jones and Curlin 1968). And positive responses of many species of hardwood shade trees to fertilization have been demonstrated in Illinois (Himelick et al. 1965 and Neely et al. 1970)

Pot tests with yellow birch seedlings revealed acute P and N deficiencies as well as the need for limestone in acid soils from northern New Hampshire (Hoyle 1969, 1970). The limestone, in addition to overcoming deficiencies, served to reduce abnormally high Mn and Al concentrations that were thought to be near toxic levels. Field tests with these amendments are now under way.

In West Virginia, a factorial experiment with potted red oak seedlings grown in a sandy alluvial soil showed that N was the primary limiting nutrient; that P applied simultaneously with N gave additional response once the N deficiency was overcome; and that further response to K was obtainable once N and P were adequately supplied

(Auchmoody 1972a).

Another pot test with both forest and old-field soils from Iowa and Missouri indicated N and P deficiencies for maximum growth of planted red oak seedlings (Phares 1971a). Additional study of growth in relation to light supply and nutrients confirmed that fertilization was necessary to obtain maximum red oak seedling production on these soils, but that fertilization could not overcome adverse effects stemming from low light intensities (Phares 1971b).

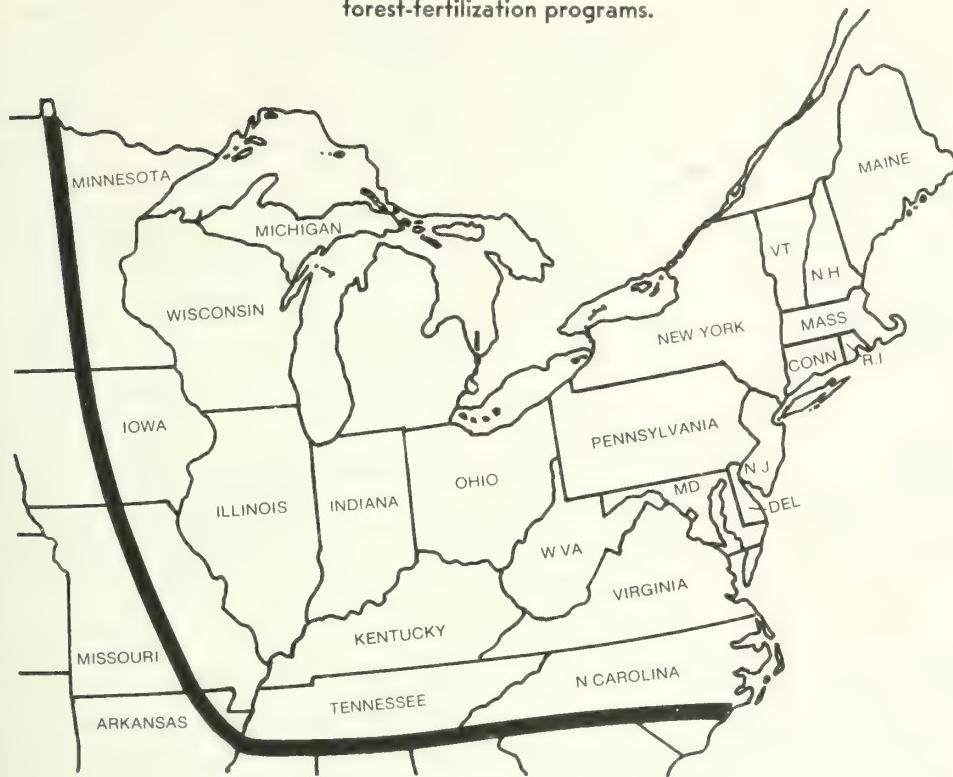
Because ultimate evaluation of forest fertilization practices must include changes in log quality as well as changes in growth rate, the effects that fertilization might have on epicormic-branch formation is an important issue. Kormanik and Brown (1969) found that heavy fertilization stimulated suppressed buds to form epicormic branches on sweetgum. A different study with red oak and yellow-poplar showed that moderate rates of N, P, and K did not stimulate epicormic branches to form, but that N had a strong tendency to increase growth of existing epicormics, particularly on the upper bole, where light was not such a limiting factor (Auchmoody 1972b).

CURRENT RESEARCH PROGRAMS

To obtain information about current fertilization activities in the Northeast we made 73 inquiries to industrial, university, and federal installations that we knew or thought might be conducting fertilization research with hardwoods.

The survey area was delineated by North Carolina and Tennessee on the south and by sections of Missouri, Iowa, and Minnesota on the west (fig. 1). We consulted the major pulp and paper companies and allied industries listed in the *Wood and Woodlands Directory* (1970), institutions offering professional education in forestry, federal forest experiment stations, the Tennessee Valley Authority,

Figure 1.—The area surveyed for information about current forest-fertilization programs.



and the Oak Ridge National Laboratory.

Each was asked if they had fertilization work in progress and, if so, to supply a brief set of statistics about it. Replies were received from more than 90 percent of those asked. The following information is based on those replies, many of which came from the people or organizations represented here at this meeting today.

In the Northeast at least 95 field fertilization studies are now under way (see appendix). Of these, 47 are being conducted by universities, 41 by federal agencies, and 7 by industry. (Field studies by seven other investigators were not known to the author at the time this report was prepared, and they are not discussed here; this work, mainly with sycamore and sweetgum, is listed in the appendix.)

Eighty-three of the 95 studies—about 87 percent—are oriented toward increasing forest growth rates. The other 12 are concerned with such issues as water quality after fertilization of complete watersheds, fertilizer/genetic interactions, effects on wood properties, and influence on seed and sap production.

Of the 83 growth studies, 29 apparently are also oriented toward identifying specific limiting nutrients while the other 54 are oriented mainly toward the degree of response that might be obtainable. It is noteworthy that optimum rates of fertilization are being studied in 29 experiments.

Seventy of the tests—about 75 percent—are concerned with established stands; and 25 deal, for the most part, with planted seedlings. The majority of tests in established stands are with trees fall-

Table 2.—Number of active hardwood field-fertilization tests, by species.

Species	Tests
1. Mixed northern hardwoods	17
2. Yellow-poplar	17
3. Black walnut	16
4. Upland oaks (primarily northern red)	16
5. Hard maple	15
6. Black cherry	8
7. Yellow birch	6
8. Aspen	4
9. Paper birch	4
10. Mixed Appalachian hardwoods	4
11. Sycamore	3
12. Red maple	3
13. White ash	2
14. Beech	1
15. Sweetgum	1
16. Basswood	1
Total ^a	118

^aTotal exceeds the number of active field tests due to inclusion of more than one species in some studies.

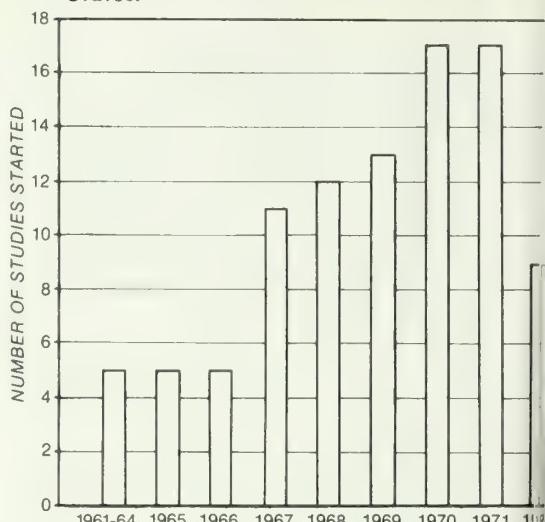
ing in the 30-to-70-year bracket, but in several studies trees up to 200 years of age have been fertilized. A number of species are involved, but the greatest interest is with mixed northern hardwoods, yellow-poplar, black walnut, sugar maple, and the upland oaks (table 2).

It is significant that 72 percent of the work under way is less than 5 years old, and 45 percent of the tests are only in their third growing season or less right now (fig. 2). Moreover, except for one small study, none is older than 10 years.

Nineteen of the tests are located in unthinned stands and 45 are in thinned stands; 13 tests in thinned stands include thinning without fertilization as a separate treatment. Thirty-one studies are with younger stock—both planted and natural—located on cutover forest land or on nonforest sites.

N is being tested either singly or in combination with other nutrients in all but five studies. The most commonly used N source was ammonium nitrate, which was used in four times as many tests as urea. Application rates for N ranged from a low of 33 pounds/acre to a high of 900 pounds/acre, but the major-

Figure 2.—Age and number of hardwood fertilization tests in the northeastern United States.



ity were between 150 and 300 pounds/acre. In only two tests were slow-release N fertilizers being evaluated.

P, applied either singly or in combination with other nutrients, was included in 66 tests—about 70 percent of the total. The use of triple superphosphate outnumbered the use of normal superphosphate by approximately 3 to 1. Application rates varied from a low of 13 to a high of 262 pounds/acre P(30–600 pounds/acre P₂O₅), but most applications were between 44 and 87 pounds/acre P(100–200 pounds/acre P₂O₅).

K was being used in 52 tests; usually although not always, in combination with N and P. The most common source of supply was muriate of potash. Application rates varied from 33 to 333 pounds/acre (40–400 pounds/acre K₂O).

Magnesium, apart from that supplied by lime, was being tested in only six studies. Lime was included in 19 test and “complete” fertilizers were being used in 20 tests. Lime has been applied at rates up to 10 tons/acre.

The experimental plots being used were generally small. Plot size varied from 0.01 acre to 10 acres, but 0.10-acre plots and smaller were common and those 0.50 acre and larger were uncommon. Most studies had multiple tree plots, but 16 studies were based only upon single trees. The most common experimental unit was individual trees (56 studies), but changes in stand productivity were being evaluated in 34 cases.

The most frequently measured indicator of response was d.b.h. (83 studies), followed by nutrient uptake (51 studies), height (48 studies), diameter growth at heights above breast height (9 studies), and foliar weight (9 studies). Other variables mentioned included water quality, epicormic branching, survival, seed production, frost resistance, root development, sap characteristics, and above-ground biomass.

Sixty-eight studies included soil analysis, plant analysis, or both. Forty-one studies involved both; 13 other studies involved soil analyses and 14 involved tissue analyses only.

Of the 83 studies oriented toward increasing growth rates, 36 reported positive response to fertilization, 10 indicated no response, and 37 were uncertain—mainly because studies were new or because measurements had not yet been taken.

STATE OF THE ART

Published results, together with interim results from studies in progress, show that we have learned many details, since 1930, about the response of hardwoods to fertilization. A status report such as this seems an appropriate place to ask: What do these details add up to? Where do we stand? What general conclusions can we draw from our past efforts?

We do not pretend that our list is complete, but we believe that the following

major conclusions provide a strong foundation for future research:

- There is unquestionable evidence that a number of hardwood species have the potential ability for responding in growth rate to fertilization. Response has occurred on a variety of sites and with a range of age classes from young seedlings to middle-aged trees. Because certain hardwoods are generally recognized as being more nutrient-demanding than conifers, there is speculation that they might respond more vigorously to fertilization. While this may be correct, it is also generally true that natural stands of these species normally occupy the most fertile sites available.
- Response to fertilization depends on the supply of essential soil nutrients relative to the nutrient requirements of the species, genetic limitations on growth, and to growth-limiting site parameters such as moisture regime, soil volume, and climate. Fertilization will not increase productivity when there are no nutrient deficiencies or when growth is limited by other factors.
- N is by far the primary growth-limiting nutrient in hardwood forests, but response from P may frequently be forthcoming after the N deficiency is overcome. Although instances exist where response has been greatest with "complete" fertilization as compared to N only, rarely has response to these other nutrients occurred when they have been applied singly without N. Liming may be necessary in highly podzolized soils because of Al and Mn toxicity. In both pot and field tests, liming has effectively reduced Mn concentrations in yellow birch and sugar maple foliage.
- Response to N fertilization, where it occurs, is rapid and detectable the first year, but often is greatest in the second

season. N increases leaf size, mass, and number; produces dark green foliage; retards leaf abscission; and may increase photosynthetic efficiency.

- The duration of response from a single fertilizer application in hardwood forests has not been clearly established. But, unlike the situation in agriculture, effects upon growth persist for several seasons. The length of time that fertilizer nutrients remain available for growth depends a great deal on the material used, the particular nutrients of concern, soil conditions, and topographic configuration of the site. Response duration from a single application of N is apparently quite variable, lasting for time spans as short as 2 years and in excess of 18 years (personal communication from R. H. Finn, based on stem analysis of trees fertilized in the 1930s on Black Rock Forest plots). Variation in loss from NH₃ volatilization and leaching of mobile NO₃ ions, particularly during the dormant season and on steep topography, is suggested as the possible cause. With P, rapid conversion of available into unavailable forms particularly in acid soils well supplied with iron and aluminum, may seriously limit the time that this element remains available for absorption.

- The amount of response obtainable from fertilization is also variable, but apparently depends on pretreatment growth rates (a function of site quality), species, and rate of fertilization. Stand density is also an important factor, and it is well known that yields may be affected as much by spacing as by any nutrient treatment. Despite the variation in response to fertilization, the data available for stands not showing obvious nutrient disorders or abnormally slow pretreatment growth rates indicate that growth may be increased on the average by as much as 80 percent.

- Field fertilization trials are now the only reliable method of identifying nutrient deficiencies. Neither soil nor foliar tests have yet been field-calibrated and perfected for diagnosis of critical nutrient regimes in hardwood forests. Although data on soil and foliar nutrient composition as they relate to response are accumulating, they are too fragmentary for reliable response predictions to be developed.
- Thus the major conclusion to be drawn from work to date must be that we have only scratched the surface of what needs to be learned about fertilization of eastern hardwood forests.

RESEARCH NEEDS

After summarizing what is now known about fertilization of eastern hardwood forests, we can now list problems that we think should be placed high on the list of research priorities. We have grouped these into five categories, focusing primarily upon practical physical aspects associated with the use of fertilizers for increasing production of wood fiber. However, it is not our intention to slight economic studies, and especially the many required fundamental studies that necessarily are associated with these leading issues. We stress the importance of investigating basic problems to the depth necessary for complete understanding.

I. Establish Additional Field-Fertilization Tests

Despite 40 years of research, we still have little definite information about how widespread and how serious nutrient deficiencies may be in the Northeast and how they can be recognized. Field-fertilization trials are now the most dependable method for identifying such deficiencies, and the only dependable method for quantifying response. And we have only begun to tackle the practical application

problems of what nutrients to apply, in what form, how much, where, and when.

Although significant increases in the number of field trials have occurred in recent years, current studies are hopelessly inadequate for providing the information needed, even for the most important species. Moreover, current tests are so diverse in nature that meaningful comparisons and syntheses of results will be most difficult.

If we are to accomplish or even make significant progress in the job of installing, maintaining, and analyzing the additional field trials needed, we must pool resources, focus our objectives, and initiate a comprehensive program of field testing. Because no single agency has the resources necessary to do this, we emphasize that a cooperative effort is paramount.

The cooperative research programs in forest fertilization at the University of Washington, North Carolina State University, and the University of Florida are outstanding examples of what may be accomplished by regional group research efforts. We do not imply that such a formalized approach to forest-fertilization problems in the Northeast is necessary or even desirable, because of great regional diversity. On the other hand, some degree of uniformity in field-plot technique and laboratory methods would be most desirable. There is also need to establish a mechanism by which collaboration between investigators could be improved.

II. Develop Diagnostic Criteria

One of the key factors of a successful fertilization program lies in knowing which nutrient or nutrient combinations are deficient and where these deficiencies occur. Probably nothing else will hasten the use of fertilizers as a means of increasing fiber production more than the development of reliable diagnostic criteria from which response can be predicted.

This is an area where pursuit of many

fundamental issues is first necessary before soil test values, tissue test values, or visual criteria can be used with any degree of accuracy or predictive reliability. Such basic questions as what type of material to sample, where should it come from, when should it be sampled, and how many samples are necessary are among the unknowns for most hardwoods. For tissue analyses, should we sample buds, bark, leaves, petioles, or sap? Which of these are most sensitive to changes in external nutrient supply and which correlate best with growth response? How about the many problems associated with sampling large trees? From what soil horizons should samples be taken to best correlate with response? What extracting solution should be used in determining available nutrients? Can useful criteria be developed on visual appearance alone and eliminate the need for soil and tissue testing? Can response be related to permanent features of the landscape? The list goes on and on.

III. Determine Effects on Environmental Quality

This is an area about which we know very little, but it is fast becoming a matter of concern because of recent broad ecological implications. What happens to fertilizer nutrients that are introduced into hardwood forest ecosystems? Do they run off and contaminate our streams? Do they find their way into deep aquifers? What portion of them may be lost to the atmosphere by volatilization? A few answers are slowly beginning to accumulate; but these questions need much greater attention, especially if fertilization of large forest areas becomes a reality.

IV. Evaluate Fertilizer/Genetic Interactions

Perhaps one of the most promising areas for fertilization studies is closely related to genetics and plant breeding. The possibility of developing superior tree strains that possess the ability for

outstanding response to intensive fertilization regimes is intriguing. There are good indications that this may be possible through a program of field selection and breeding of individuals showing exceptional response in field-fertilization tests.

V. New Approaches

The standard approach in almost every forest fertilization test has been to broadcast plant nutrients upon the soil, usually in a single application. This has been done continually, yet we know that N retention is difficult and that P can be quickly converted to chemical forms that are not available for tree growth. Furthermore, we know that certain N fertilizers, particularly urea, are prone to large losses from volatilization of ammonia.

Is direct application of nutrients to the soil really the best way to fertilize? Do

we have to tolerate the risk of nutrient loss by leaching and volatilization, chemical tie-up, or use by undesirable vegetation? What about foliar application of nutrients or direct injection of nutrients into the tree whereby these risks could be completely eliminated? Could fertilizers with slow-release characteristics such as the metal ammonium phosphates, urea-formaldehyde, sulfur-coated urea, and resin-coated urea be substituted for the water-soluble formulations now in general use?

These possibilities, although known for some time, are largely unexplored. But their importance cannot be overstressed because widespread economic acceptance of forest fertilization may depend heavily upon development and use of materials that release nutrients slowly and will maintain response over long-term intervals without jeopardizing our water supplies or environment.

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APPENDIX

Directory of Current Forest-Fertilization Research with Hardwoods

Species	Investigators ¹
1. Aspen	15, 39
2. Basswood	1, 2, 37
3. Black cherry	2, 3, 4, 5, 7, 23, 24, 25, 31, 37
4. Black walnut	8, 10, 30, 46, 47
5. Mixed northern hardwoods	17, 19, 28, 29, 37
6. Red maple	2, 4, 11, 23
7. Sugar maple	4, 5, 7, 11, 17, 21, 23, 24, 28, 31, 33, 36, 37, 42, 46, 49
8. Sweetgum	8, 9, 13, 18, 20, 22, 40, 41
9. Sycamore	8, 13, 14, 18, 20, 22, 40, 41, 47, 48
10. Upland oaks	1, 2, 6, 9, 16, 25, 26, 27, 32, 35, 37, 38, 43, 44, 45, 46, 47, 50
11. White ash	25, 31, 37
12. Yellow-poplar	1, 2, 9, 12, 16, 25, 31, 34, 46, 47, 51

¹Numbers refer to the following investigators.

1. Gerald M. Aubertin
Northeastern Forest Experiment Station
Timber and Watershed Laboratory
Parsons, W. Va. 26287
2. L. R. Auchmoody
Northeastern Forest Experiment Station
Forestry Sciences Laboratory
P. O. Box 928
Warren, Pa. 16365
3. R. E. Barlow
Timberland and Forest Products Division
Hammermill Paper Company
East Lake Road
Erie, Pa. 16512
4. A. L. Bennett
Armstrong Forest Division
Texas Gulf Sulphur Company
Johnsonburg, Pa. 15845
5. John V. Berglund
Associate Professor of Silviculture
State University of New York, College of Forestry
Syracuse, N.Y. 13210
6. T. W. Bowersox
School of Forest Resources
Pennsylvania State University
University Park, Pa. 16802
7. Robert E. Bramhall
The J. P. Lewis Company
Beaver Falls, N. Y. 13305
8. Dwight Brenneman
North Carolina Forest Service
Route 10, Box 1
Morganton, N.C. 28655
9. Edward R. Buckner
Department of Forestry
The University of Tennessee Knoxville, Tenn. 37916
10. W. R. Byrnes
Dept. of Forestry and Conservation
Purdue University
Lafayette, Ind. 47907
11. Willard H. Carmean
North Central Forest Experiment Station
Folwell Avenue
St. Paul, Minn. 55101
12. Franklin C. Cech
Division of Forestry
West Virginia University
Morgantown, W. Va. 26506
13. Howard Daniel
Hoerner-Waldorf Corp.
Halifax Timber Division
Roanoke Rapids, N.C. 27870
14. Charles B. Davey
School of Forestry Resources
North Carolina State University
Raleigh, N.C. 27607
15. Dean Einspahr
Institute of Paper Chemistry
Appleton, Wis. 54910
16. R. E. Farmer
Division of Forestry, Fisheries and Wildlife Development
Tennessee Valley Authority
Norris, Tenn. 37828
17. S. M. Filip
Northeastern Forest Experiment Station
Forestry Sciences Laboratory
Durham, N.H. 03824
18. Jack Formy-Duval
Federal Paper Board Company, Inc.
P. O. Box 1249
Lumberton, N.C. 28358
19. F. F. Gilbert
School of Forest Resources
University of Maine
Orono, Me. 04473
20. L. W. Haines
School of Forest Resources
N. C. State University
Raleigh, N.C. 27607
21. Peter R. Hannah
Department of Forestry
University of Vermont
Burlington, Vt. 05401

22. Robert Heeren
Union Camp Corporation
Franklin, Va. 23851
23. R. J. Hutnik
School of Forest Resources
The Pennsylvania State University
University Park, Pa. 16802
24. Albert L. Leaf
Professor of Forest Soil Science
State University College of Forestry
Syracuse, N.Y. 13210
25. Nelson S. Loftus, Jr.
Silviculture Laboratory
SPO Box 1037
Sewanee, Tenn. 37375
26. Walter H. Lyford
Harvard Forest
Petersham, Mass. 01366
27. Donald L. Mader
Department of Forestry and
Wildlife Management
University of Massachusetts
Amherst, Mass. 01002
28. Russell A. Oettel
American Can Company
Rothschild, Wis. 54474
29. P. C. Perkins
Oxford Paper Co.
Rumford, Maine 04276
30. Robert E. Phares
Forestry Sciences Laboratory
Southern Illinois University
Carbondale, Illinois 62901
31. N. A. Richards
State University of New York, Col-
lege of Forestry
Syracuse, N.Y. 13210
32. Nelson F. Rogers
North Central Forest Experiment
Station
Salem, Mo. 65560
33. Stephen Shetron
Forestry Center
L'Anse, Mich. 49946
34. R. D. Shipman
School of Forest Resources
Pennsylvania State University
University Park, Pa. 16802
35. William E. Sopper
School of Forest Resources
Pennsylvania State University
University Park, Pa. 16802
36. Douglas M. Stone
North Central Forest Experiment
Station
Northern Hardwoods Laboratory
806 Wright Street
Marquette, Mich. 49855
37. Earl L. Stone
Department of Agronomy
Cornell University
Ithaca, N.Y. 14850
38. Benjamin Stout
Department of Horticulture and
Forestry
Rutgers University
New Brunswick, N.J. 08903
39. Edward Sucoff
School of Forestry
University of Minnesota
St. Paul, Minn. 55101
40. T. W. Sweetland
Continental Can Company, Inc.
P. O. Box 340
Hopewell, Va. 23860
41. Thomas A. Terry
Weyerhaeuser Corporation
P. O. Box 1391
New Bern, N.C. 28560
42. Russell S. Walters
Northeastern Forest Experiment
Station
Federal Building
Burlington, Vt. 05401
43. W. W. Ward, Director
School of Forest Resources
The Pennsylvania State University
University Park, Pa. 16802
44. Richard F. Watt
North Central Forest Experiment
Station
Agriculture Building, University of
Missouri
Columbia, Mo. 65201

45. G. W. Wendel
Northeastern Forest Experiment
Station
Timber and Watershed Laboratory
Parsons, W. Va. 26287
46. D. P. White
Department of Forestry
Michigan State University
East Lansing, Mich. 48823
47. E. H. White
Department of Forestry
University of Kentucky
Lexington, Ky. 40506
48. James Willis
Chesapeake Corporation of Virginia
West Point, Va. 23181
49. Harry W. Yawney
Northeastern Forest Experiment
Station
Federal Building,
P. O. Box 958
Burlington, Vt. 05401
50. W. A. Van Eck
Department of Agronomy and Ge-
netics
West Virginia University
Morgantown, W. Va. 26506
51. J. P. Vimmerstedt
Ohio Agricultural Research and
Development Center
Wooster, Ohio 44691

LANDSCAPE GEOCHEMISTRY AND FOREST FERTILIZATION

by J. A. C. FORTESCUE and D. BURGER, respectively with
*the Department of Geological Sciences, Brock University,
St. Catharines, Ontario; and Research Branch,
Ontario Ministry of Natural Resources, Maple, Ontario.*

ABSTRACT. An introduction to the subject of landscape geochemistry, focusing attention on relationships between landscape geochemistry and forest fertilization. An orientation landscape geochemistry project is described, with special reference to a method for determining the element status of forest trees and stands, which is believed to be independent of within-season or season-to-season variation in chemical composition.

GEOCHEMISTRY is essentially the study of the role of all elements in the Periodic Table in the synthesis and decomposition of natural materials of all kinds. The broad scope of geochemistry was stressed by the pioneer workers in the field, including V. I. Vernadski in Russia, F. W. Clarke in America, and V. M. Goldschmidt in Norway, who laid the foundation of the subject during the early years of this century. Further information about the history of geochemistry may be found in the classic textbook by Rankama and Sahama (1950).

LANDSCAPE GEOCHEMISTRY

Landscape geochemistry is concerned with the circulation of chemical elements at or near the surface of the earth where the lithosphere, hydrosphere, atmos-

sphere, and biosphere interact. Landscape geochemistry does not stand alone, but draws heavily on information obtained from other disciplines, including chemistry, physics, geology, geophysics, geochemistry, geomorphology, biology, and ecology.

The concept of holism is at the heart of landscape geochemistry, because it is believed that a systematic study of the circulation of chemical elements in many components of landscapes will frequently provide a kind of information different from that obtained from detailed studies of particular landscape components. For this reason the study of landscape geochemistry is often more concerned with *volume* units of landscape than with areas. Such volumes may vary in scale from less than a cubic metre to the whole surface of the globe.

Systematic landscape geochemistry

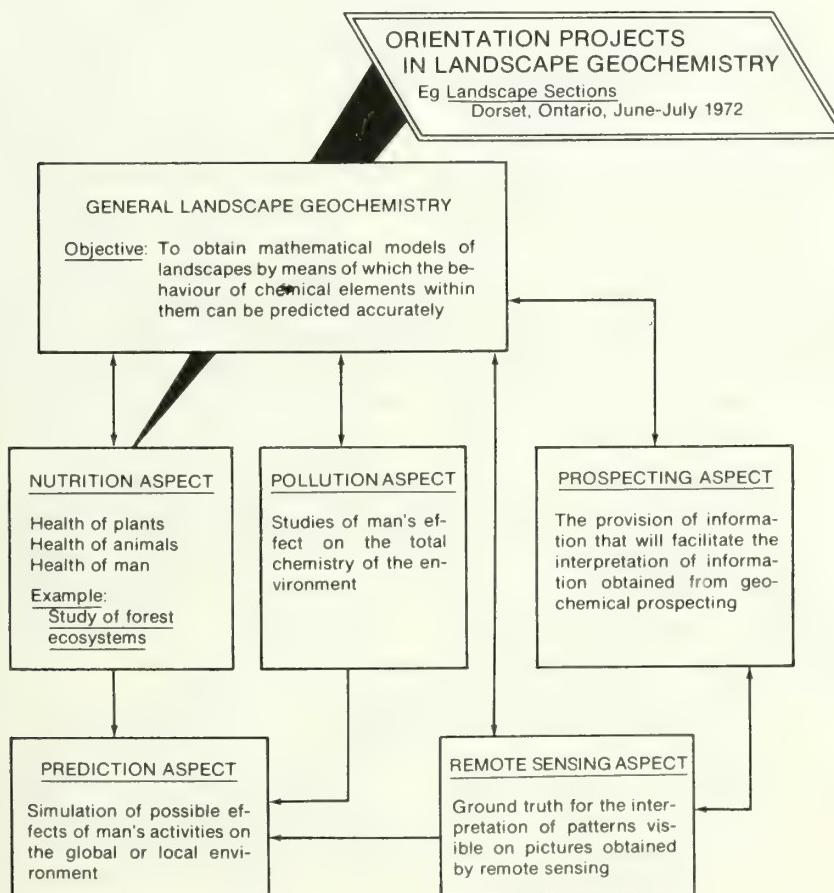
study has been greatly stimulated by scientific advances during the 1960's. For example, it is now possible to determine the content of over 60 chemical elements in the same sample at the same time, some at concentrations far below 1 p.p.m. (Morrison 1972); and the use of the electronic computer combined with modern methods of systems analysis (Reichle 1970) indicates that reliable mathematical models for simulation of the circulation of chemical elements in landscapes may be prepared during the near future.

Modern landscape geochemistry has gradually evolved from foundations laid by Polynov (1937), Perel'man (1961), Glazovskaya (1963), and other workers. Landscape geochemistry is closely re-

lated to other holistic approaches to the description of landscapes, including that by Sukachev and Dylis (1964) in Russia and those by Hills (1953) and Krajina (1965) in Canada. Several practical applications of the landscape-geochemistry approach are being actively researched (fig. 1).

One serious problem that faces research workers in landscape geochemistry is the establishment of conceptual models of nature that can facilitate the interchange of chemical and descriptive information between the different aspects of the subject. Much progress in this field may be expected in the near future.

Figure 1.—The scope of landscape geochemistry.



A SIMPLE EXAMPLE

At the present state in the evolution of landscape geochemistry, it is desirable to carry out research on relatively simple conceptual models of nature to establish patterns of behavior of elements under ideal conditions. Many attempts to study the details of the circulation of chemical elements (for example around mineral deposits) in landscapes have provided inconclusive results because the landscapes studied were too complicated to provide simple statements of the behavior of chemical elements concerned. Experience with systems analysis suggests that although complexity can be added to simple landscape models, it is not always possible to subtract the effects of complexity from an already relatively complex situation.

A relatively simple conceptual model of a landscape was drawn in March 1972 as a preliminary to finding a field area for a summer field project (fig. 2). This conceptual model includes a part of the Earth's surface where the lithosphere, biosphere, and atmosphere interact (the forested hillslope); where the biosphere and hydrosphere interact with the atmosphere (the forested bog); and where the hydrosphere interacts with the biosphere and atmosphere (the lake).

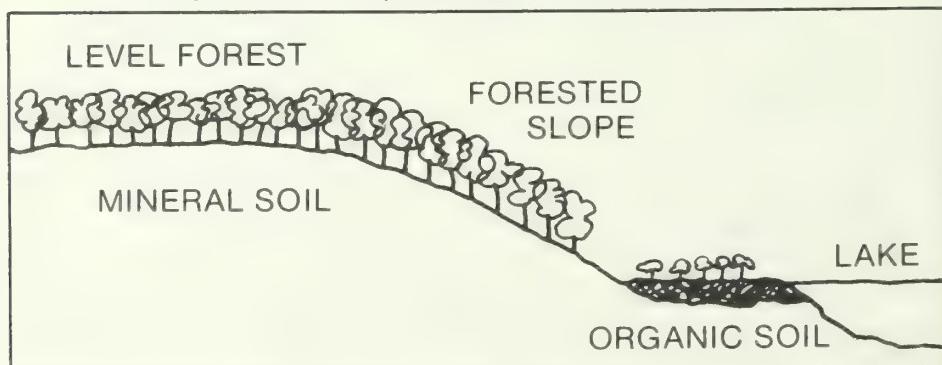
In addition a moisture gradient is to

be expected between the hilltop and the hillbottom, which will result in variations in the morphology of the soil cover types and variations in the distribution of the tree species comprising the forest cover. It should be noted that the hillslope models (fig. 2) is essentially a landscape section with no thickness. In practice it was decided to study a 20-m. wide strip of country as though it were a section rather than a volume unit of country. When the experiment was devised, it was decided to restrict preliminary investigations to samples from soil profiles and tree crown branches.

In planning landscape geochemical projects, three hierarchies involved in the classification of matter should be considered in relation to each other. In the proposed study the hierarchy of space (or more correctly scale) was considered to be such that the traverse would be 500 m. long. If it were shorter than this it would be likely to be too complex to study, and if it were more extensive it would be impractical to study on the required scale in the time available.

The second hierarchy studied is that of time. The aim here was to sample the soils and trees within a single instant of time (some 3 weeks in duration) during June and July 1972. This would provide an overview of the distribution patterns for elements in soils and plants at this

Figure 2.—A conceptual model of a landscape section.



time. A second purpose of the investigation would be to use 10 years of branch growth as a history book for the growth and element status of the trees growing in the stand. Details of this approach to the estimation of the element status of forest trees have been described previously (*Fortescue and Hughes 1971*).

The third hierarchy to be considered was the complexity of the materials selected for chemical analysis. In the case of the mineral soils, the chemical data would be expressed as parts per million of an element in the cold hydrochloric acid soluble part of the oven-dry -80 mesh fraction of the soil. In the case of the bog soils, the basis for the chemical analysis would be the aqua regia soluble portion of the dry ashed material expressed on an oven-dry basis. The content of the chemical elements in the tree branch material would be expressed as parts per million oven-dry weight. All chemical determinations were to be carried out using a Perkin Elmer 403 Atomic Absorption apparatus with automatic sample changer and Teletype print-out attachment.

The elements to be included in the study would represent nutrients, micronutrients, and nonessential elements (*Fortescue and Marten 1970*). In practice, data were obtained for Mg, Mn, Fe, Cu, Zn, Pb, and Al. Only data for the micronutrient manganese and the non-nutrient element lead is discussed here in relation to the soils and plants, although estimates will be included for all seven elements in the tree branch material because this data is of particular interest to scientists involved in forest fertilization.

THE SECTION AT DORSET, ONTARIO

The air photographs of an area of some 200 square miles situated in the vicinity of the town of Dorset, Ontario (some 120 miles north of Toronto), were studied to discover a landscape section of the type described above and illustrated on figure

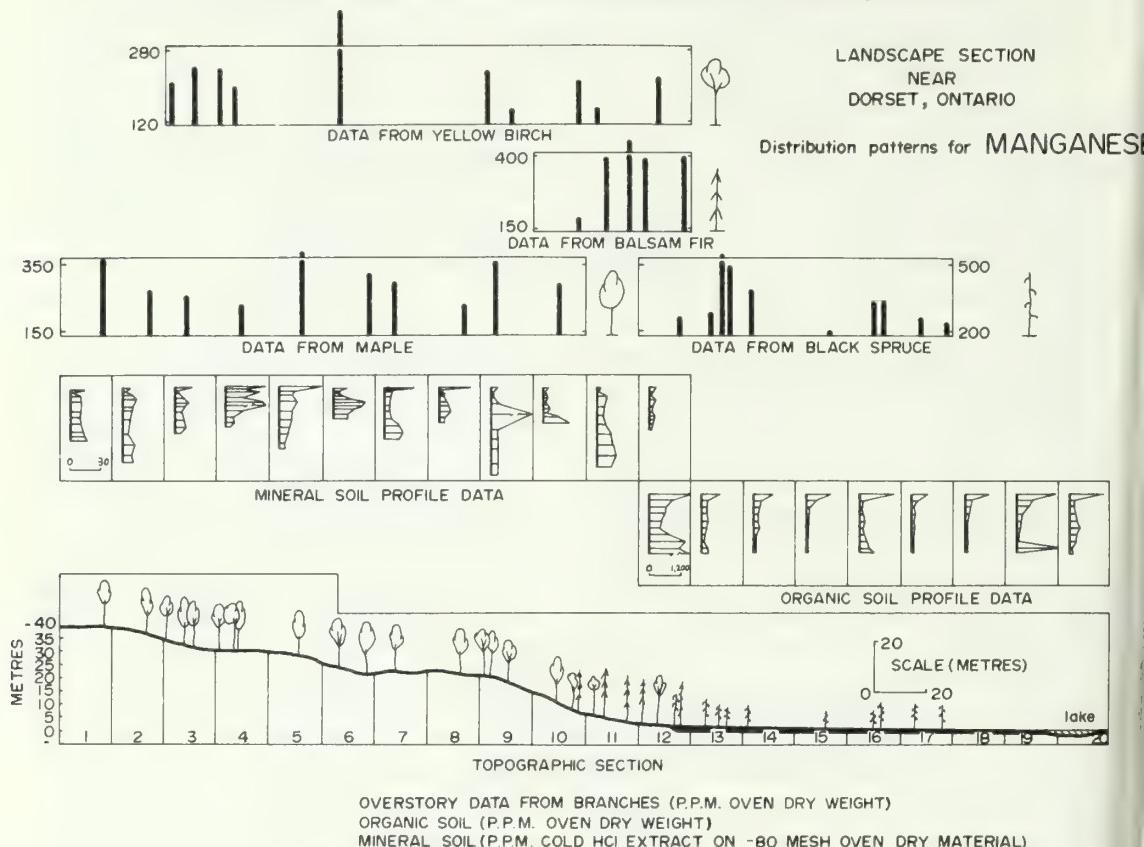
2. After 12 possible sites had been selected, 11 were rejected on the basis of laboratory, airborne, or ground investigation.

The section finally chosen closely approximates to the conceptual model (fig. 3), and is located some 8 miles north and east of the town of Dorset. The section is 400 m. long, extending from a hilltop to a small lake. Twelve soil pits were dug at regular intervals down the slope and nine bog cores were obtained from the organic terrain. Individuals of four species of tree maple, black spruce, balsam fir, and yellow birch (fig. 3)—were chosen for study. Ten soil samples were taken from profiles exposed in each pit and ten samples of bog material from each borehole. It should be noted that the maple trees were taken from the hillslope, the black spruce trees from the organic terrain, the balsam fir trees from the transition between the mineral and the organic terrain, and the yellow birch from different locations on the slope.

Data for the content of Mn and Pb in the soils, and average 1965-66 branch-growth samples for the trees, are plotted on figures 3 and 4. These plots are on a logarithmic scale to match those plotted on figure 5. It is evident that the vertical distribution patterns for Mn in the mineral soil differ from those for the organic soils. Enrichment of Mn at the surface is evident in all the organic soils and in the soils from plots 3, 4, 5, 6, 7, and 8. The distribution of Mn in the subsoil appears to vary in relation to the depth of the soil profiles.

The Mn content of the black spruce branches reaches a maximum some 30 m. from the edge of the bog. This suggests, but does not prove, that there is an edge effect along the margin of the bog, which affects the uptake of Mn by the spruce. It would be interesting to know if this is related to the higher amount of Ca available to plants growing on the bog margin. The data for Mn in the branches of maple and yellow birch does not appear

Figure 3.—Distribution patterns for manganese in a landscape section.



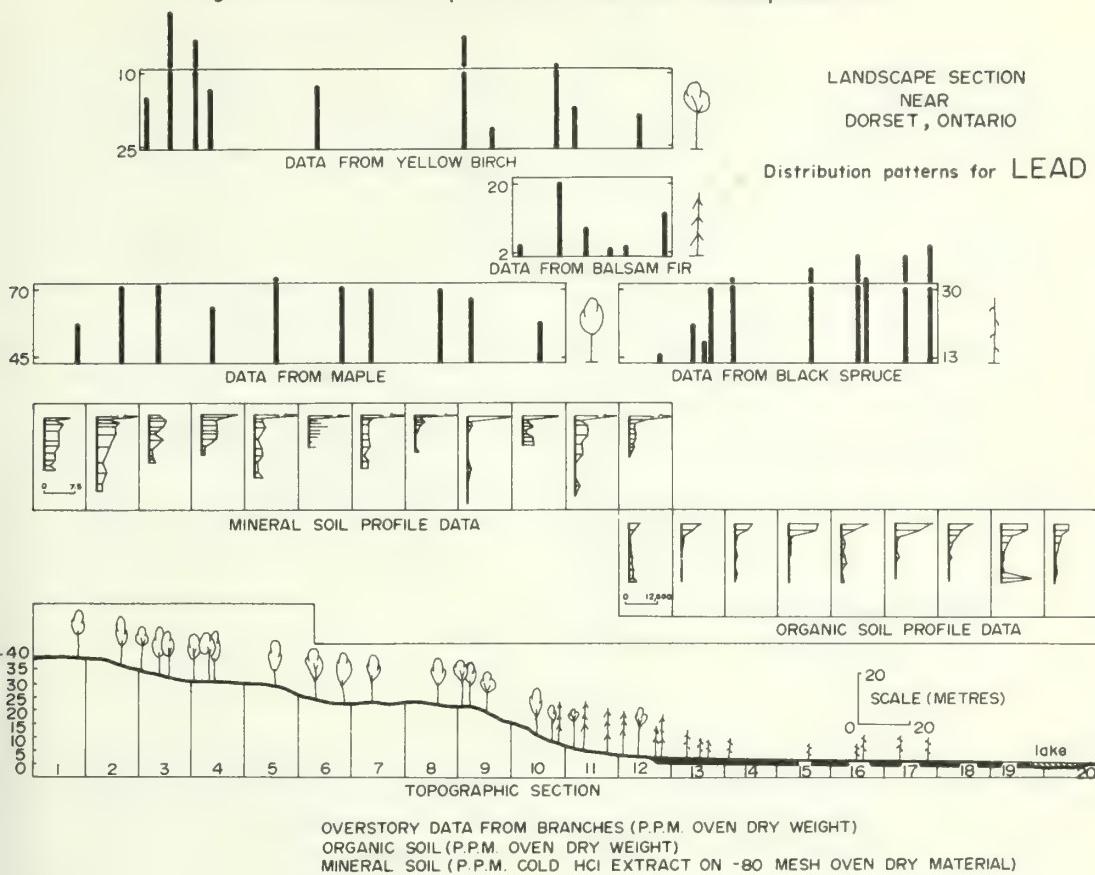
to have consistent trends within it. In the case of balsam fir the uptake of the element appears relatively low on the well-drained mineral soil.

The distribution patterns for Pb (fig. 4) are different from those for Mn in the mineral or the organic soil. The enrichment of Pb in the organic layers of both types of soil may be natural or may result from atmospheric fallout. Two observations can be made regarding the distribution of Pb in the trees: First the content of Pb increases in the black spruce branches towards the lake; and second, the Pb content of yellow birch is highest at the hilltop.

It should be stressed that these observations for Mn and Pb are included here

as examples of the kind of distribution patterns that are involved in a holistic approach to the geochemistry of a landscape section. Other patterns, some of them more marked than those described here, were found in the data sets for the other five elements included in the study. Although the techniques of sample collection and chemical analysis used here may be relatively crude, the important conclusion from this orientation study is that, with modern equipment, it is possible to carry out experiments of this type relatively rapidly and cheaply. The whole Dorset project was carried out by four people in less than 2 months. This includes sample collection, sample preparation, and chemical analysis of

Figure 4.—Distribution patterns for lead in a landscape section.



over 600 samples for seven elements each, and the preparation of a draft report.

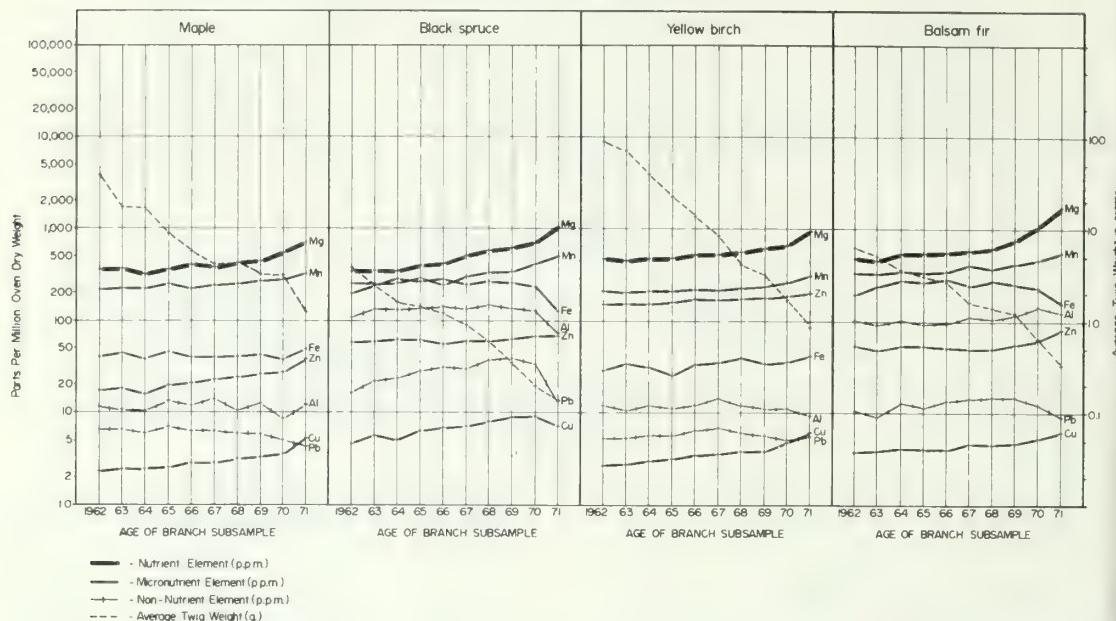
ELEMENT STATUS OF FOUR TREE SPECIES

Of particular interest to scientists involved with forest fertilization research are the estimates of element status for the four tree species growing at the Dorset site (fig. 5). The technique used to obtain these data (fig. 5) has been described in detail (*Fortescue and Hughes 1971*). Briefly, each tree of a given species selected for sampling is felled, and branch-growth sections from the upper

crown representing each year's shoot elongation over a 10-year period are separated and analysed separately. Thus 10 chemical analyses for each element are obtained from each tree. Data for branch subsamples of the same age for the different individuals of the same species are averaged to provide points on concentration lines for each element (fig. 5). After subsampling, the branch subsamples are oven-dried, weighed, and counted, and the average twig weight of each subsample is obtained. These data are also averaged for all trees and plotted on figure 5 as an indication of the tree growth rate during the 10-year period.

With this technique it is believed, but not yet proven, that estimates of the ele-

Figure 5.—Estimates for the element status of branches from four species growing on the Dorset landscape section.



ment status of the trees are obtained that are free from within-season and season-to-season variations in chemical composition. It is currently believed that the most reliable estimates are those from branch subsamples that are too old to be seriously affected by the processes associated with the growing shoot and small enough so that a reliable estimate of the average twig weight may be obtained. This is the reason for using the arithmetic averages of element content for the 1965 and 1966 growth, which are plotted on figure 3 and figure 4.

It is evident (fig. 5) that the growth rates for branches of the two deciduous species were similar and that the coniferous species grew slower than deciduous trees. The curves for Mn were—as expected—highest of all elements in the branches. The content of Mn in the branches tends to increase towards the growing shoot, which is best illustrated by balsam fir. In general, the curves obtained for the four micronutrient elements were similar to those obtained for

Mn except that in the case of Fe (and in black spruce, Cu as well), there was a decrease in concentration in the younger branch samples.

The significance of this observation is not yet clear. As expected, the concentration levels for the micronutrients are different in the deciduous and the coniferous trees. Birch is known to be an accumulator of Zn, and this effect is seen clearly in figure 5. The behavior of the two nonnutritive elements—Pb and Al—is of particular interest because in all cases the content of these elements was found to decrease towards the growing point of the branch. This effect is most marked in black spruce trees.

It seems clear that the branch method of element status determination provides information that may be of particular interest in forest fertilization research. For example, if an application of N fertilizer had been applied to the forest in 1966, the effect on the branch subsample growth would be seen in data for subsequent years on the diagram, together

with the effect on the relative proportions of the other nutrient and nonnutritive elements in the branches.

But one must not be prematurely optimistic about this approach because it is known that some elements are translocated within branches. This may complicate to an unknown extent the interpretation of data obtained from the proposed technique when it is applied to forest trees, or stands, after fertilization. Consequently more research is required to solve these problems. However, from the viewpoint of landscape geochemistry, the branch method may be suitable for the preparation of general estimates of the element status and growth of trees, which can be directly compared with others obtained from the same tree species growing in different areas.

DISCUSSION

It should be stressed the approach adopted in the Dorset project is in the nature of an orientation survey designed to obtain experience with the approach in forested landscapes. It is hoped that this experience will stimulate further thought and research along these lines in the near future.

Forest-fertilization research is a special case of a more general subject involving the geochemistry of landscapes. A simple conceptual model of a forest hillside has been used to illustrate some principles of landscape geochemistry that may be applicable to forest-fertilization research. More research along these lines is required before the importance of the approach described here can be fully evaluated.

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CRITIQUE: FOREST FERTILIZATION—RETROSPECT AND PROSPECT

by PETER J. RENNIE, *Program Coordinator, Soils;*
Program Coordination Branch, Canadian Forestry
Service, Department of the Environment, Ottawa.

ABSTRACT. Twenty-two formal contributions at the Symposium included original research and reviews of overall regional objectives, economic and human relationships, fiber production, special crops and situations, practical and theoretical methodologies, and effects of fertilization on water quality, streamflow, wildlife, and insect and disease organisms.

IT IS BECOMING the fashion for critique discussants gravely to survey their rapidly evaporating audience, to commiserate on the difficulties of summarizing even further the many already highly condensed papers, then to embark bravely on one of two courses: either to abandon the papers and foist an essentially subjective viewpoint on the audience, or to adhere slavishly to the papers and regurgitate once again their summaries.

I propose to avoid these pitfalls, possibly by falling between two stools and making a pitfall of my own! When I reflect on past fertilization meetings, on the structure and content of this particular one, and on the invigorating discussions and atmosphere that have permeated our proceedings over the past few days, I see nothing to commiserate about. I can only

feel a sense of euphoria by having participated in what can fairly be described as a milestone event in the development and progress of forest fertilization.

At first sight many, along with Professor Stone, must have questioned the basis of our regional framework. When I got out map and compass to see what a circle with a radius of 465 miles centered on Warrensburg might embrace, so blue and endless was the ocean that it seemed that a sextant was required more than a compass! And when I doubled the radius to allow for the sports-car enthusiast and the Canadian programs of western Ontario and the more northerly parts of the Appalachian system, the region then appeared to embrace an impossible diversity, ranging from the tundra of Hudson Bay to the tropics of Florida—not excluding, of course, Bermuda!

In reality, no one is suggesting the inflexibility of a particular geometrical shape to define our region. Indeed, however wide or near particular fertilization programs might be in the Northeast, they are in fact characterized by three important features. First, they are situated in the most densely populated area of North America. Second, they are located in forests or situations where through demand or activity there is either a stress condition or an early likelihood of one. Third, they are where they have a potential for impinging upon very large numbers of the public, either obviously or less obviously.

Other characteristics of the Northeast may be invoked and debated, such as a greater or lesser degree of continentality in climate, a very considerable influence of quaternary glaciation, and so forth; but the features that serve to unify and provide pertinency to our Symposium's dual theme are those just described, which stem from the intensive utilization and management of resources in an increasingly populated land. What is relevant to our region may not be relevant to other regions today, but could well be tomorrow, when their levels of utilization and population attain those of the Northeast. Therefore, just as the pioneering work on potassium nutrition conducted here in the Pack Forest two decades ago sparked interest, endeavor, and progress far beyond its original context, so there are good reasons to suppose that this novel Symposium and its new way of looking at fertilization will be the forerunner of many others.

Insofar as it is possible to split a symposium comprising several interrelated arts, the more environmental aspects will be discussed by Kenneth Reinhart, whereas the more traditional aspects of nutrition are to fall to me. For convenience, I propose to adhere to the historical pattern of development of our discipline and discuss nutritional aspects first.

SUBJECT MATTER

In concept, our Symposium is regional in scope and embodies a dual theme, stemming from a consideration of forest fertilization in an environmental context.

The 22 formal contributions may be grouped in a number of ways: the one that follows is merely a particular one and should not be taken to initiate any futile demarcation dispute. Five main groups of papers can be identified.

The first two papers (by Stone and by Hughes & Post) provide the framework of our endeavor by discussing overall objectives, economics, and human relationships.

The second main group comprises seven papers. Four of these (Safford, Krause, Auchmoodly & Filip, and von Althen & Ellis) reveal the many regional programs concerned with fiber production in coniferous and hardwood crops. The other three papers (Yawney & Walters, Czapowskyj, and Richards & Leonard) deal with special forest crops and situations—Christmas trees, spoil banks, urban forestry—that have strong environmental links and might well be classified in this way.

The third group is methodological in nature. Two papers (Gagnon, Beaton) are oriented practically, to describe the significance and potential of new fertilizer materials and their application. Strong environmental links are evident here too. Two other papers (Mader, Armson) are oriented more theoretically, dealing with procedures for diagnosing nutrient requirement and growth response. The fifth paper in this group (Gladstone & Gray) warrants separate identity by its representation of the important but neglected aspect of wood quality.

The fourth group comprises two important papers (Brett, Weetman & Hill) that bridge the traditional and newer aspects of fertilization. One shows how a number of different disciplines are being

built into a more synoptic and ecological understanding of the growth response to fertilization: the other reminds us of the complex system of producers, consumers, and decomposers that can be disturbed in various ways when the forest ecosystem is manipulated through fertilization.

Finally, there is a fifth group of five papers (Werner, Hornbeck & Pierce, Aubertin *et al.*, Behrend, Shigo), all intimately concerned with the environmental effects of fertilization—be they water quality, streamflow, wildlife, or insect and disease organisms.

One is obliged to ask in general terms: How well or inadequately do the five sections or 22 papers cover the waterfront? Bearing in mind the wealth and diversity of the many facets that go to make up forest fertilization, and remembering the makeup of the Gainesville and Finnish symposia sponsored by the Tennessee Valley Authority and International Potash Institute, we may readily see that our Symposium is roughly half their size. With this obvious constraint, the coverage is remarkably good. There is little if any repetition: most conventional topics are included; and the Symposium is novel and outstanding by bringing together for the first time solid contributions on numerous nutritional and environmental aspects.

One notable omission is nursery production. Although it is fair to say that progress on this front has been so outstanding that no unsurmountable problems remain, it is salutary to recall that much of this success has been achieved by diagnostic and other procedures whose adoption for other stages of forest growth is still in course of investigation. Nursery research still warrants close inspection. These are, moreover, days of change: container-grown stock with special nutrient regimes is increasingly supplementing or supplanting traditionally

raised bare-root stock. Such developments are worth studying.

Perhaps not so much an omission rather than an elusiveness is the reporting of exactly how much commercial fertilization is going on. There seems to be a need for a better specification of what is research and what is regular practice. I realize, of course, that sometimes a sharp separation between the two cannot be made, for company fertilizer trials are often semi-operational, and most programs are as yet research; but the researcher can very easily remain in a fool's paradise if he loses sight of the relevance of the technique he is researching and is not made aware of problems as seen and experienced by the forest manager. Therefore, I believe our Symposium, along with others, could have been strengthened by a more obvious representation of commercial practice and the forest manager's viewpoint.

Although there are outstanding exceptions, there did seem to be more opportunity to specify the particular ecological conditions within which studies were conducted. We all know the cost of research and will certainly not easily forget Dr. Stone's figure of \$100 per corn plot. There is an increasing need to know and cite the ecological parameters of a study, so that its results may be extrapolated successfully for the maximum possible benefit. Perhaps a final absence to be noted are those highly specialized physiological, soil, or other studies that can sometimes open up vistas of new approaches and practices.

More than counterbalancing these minor lacunae, however, is a solid middle-of-the-road coverage that incorporates many valuable recent results and reviews in the traditional areas of our subject, together with many thought-provoking and stimulating ideas in the newer environmental aspects.

HIGHLIGHTS OF NUTRITIONAL ASPECTS

We might usefully enunciate a general framework objective for all forest-fertilization research. Quite simply, we seek a reliable, economic, and environmentally safe technology. For the Northeast, with its twin pressures of utilization and population, a number of regional objectives have been identified, all of which fall within this framework objective. These regional objectives are real. They are precursors of situations that can be visualized as becoming more widespread elsewhere when population and utilization pressures build up.

The specification of regional objectives is both an assurance and a warning. Their detail should alleviate any fears environmentalists might entertain that fertilization signifies some wholesale attack upon the landscape. Specific situations have been identified. These should serve to remind nutritional researchers of the socio-economic forces that make certain situations relevant and others not so. A focusing of research effort is facilitated. This is nowhere more important than in costly and ambitious programs of cooperative field-trials: only the relevant should be embraced, not an entire ecological spectrum. The objectives remind us of the sometimes forgotten situations—nurseries, Christmas trees, sugarbush, spoil banks, etc.—where more has been done from the research stage to a successfully applied commercial practice than with adult forests. Aside from their intrinsic merits, such studies have valuable pointers to impart for those concerned with fertilization at establishment and semimaturity.

The plea for more regional cooperation warrants special support. Scarcity of expertise to round out the many specialties implicit in forest fertilization is one reason. Another is the way programs frequently develop in isolation. New programs are continually being started with-

out the results of past efforts being sufficiently analyzed, publicized, and heeded. The variety of approaches and methodologies often renders comparison impossible. The viewpoints of company forester, fieldman, and boffin can remain compartmentalized. The solution of these problems is not simple, and I am not sure that at this stage in the state of our art we should seek to impose excessive standardization and inflexibility. What seems optimal today could be obsolescent tomorrow. Nevertheless a more intimate way of working could do much to eliminate the less promising and to promulgate the best from other disciplines.

We are fortunate to have available a lucid contribution on the key role of economics (Hughes & Post). Not only do we see the value of the field experiment underlined, but we are presented with a very balanced argument for implementing field experiments whose designs permit economic analysis. There is little doubt that appreciable past field experimentation has been suboptimal in design and that we are moving into a period when field designs will receive far more scrutiny. Usually a chronological series of field experiments are required to specify an optimum combination of nutrients and dosages: it is reassuring to know that, provided experiments within the series are well designed, economic analysis need not be delayed, although it is obviously desirable if a multivariable design able to elicit the optimum treatment can be implemented at the start. As a particular type of multivariable design—the rotatable factorial—has attracted appreciable attention, it is worth stressing that this is not necessarily the most appropriate of the multivariable designs available to provide a response-surface. Of particular value is the discussion on raising the allowable cut, for much fertilization centers on the semimature rather than the preharvest growth-stage, on the assumption that increased growth at semimaturity is just as economic.

Programs concerned with adult conifers in the Northeast display similarities and differences. Several species under investigation are the same in both the United States and Canada. Commercial practice is as yet very limited, in spite of encouraging experimental results. One wonders why. Does experimentation stop short of being taken to the pilot-scale and full-scale demonstration? Does the inadequate publication of field experimentation restrict awareness? Is industry insufficiently motivated? Are some of the field trials untrustworthy? Is there inadequate contact among different agencies?

These and other questions need to be answered to remedy an unsatisfactory situation, for it is clear that research is generating the most encouraging growth-responses to fertilization. Of particular interest is the similarity in response reported for black spruce over wide geographical areas (Krause) in respect of N and N+P treatments. This gives strong support to Safford's plea to initiate combined research and application now, for the more promising recipes are already at hand. Differences between our two countries seem to be a greater interest in K in the United States compared with N-P-K combinations in Canada, a greater use of NH_4NO_3 rather than urea in the United States, and the rather understandable greater interest in conifers in Canada.

For hardwoods, on the other hand, there is greater activity in the United States: Auchmoodie & Filip's paper is a masterly summary and reference document. Once again, however, we see the relatively small interest by industry and wonder how much commercial practice is actually going on. The results of these authors' questionnaire-enquiry are most encouraging. It is now possible to predict with fair precision the blend of nutrient-elements and dosages likely to give positive growth-responses.

One wonders, again, if lack of publicity has militated against commercial applica-

tion. Perhaps such questionnaires, pains-taking analyses, and the distillation of highlights from a mass of unpublicized experimentation is a labor-of-love task we have insufficiently provided for. The Canadian contribution in this area (Ellis & von Althen) underlines the point made earlier on how specific rather than general are interests in fertilization. In the challenging problem of fertilizing at establishment, it is commendable to see both a positive and a negative result critically discussed. Too often a negative result has been miscalled a negative experiment and buried. We need, I think, a comprehensive yet simple system of recording all field experiments started, with sufficient detail of their ecological and environmental parameters to permit analysis at any time for a variety of purposes and hypotheses.

In the case of the special crops—sugarbush and Christmas trees (Yawney & Walters)—we are shown how important it is to optimize fertilizer treatments in respect of certain highly specific attributes of the final crop rather than for some general growth characteristic. It is interesting to see that for sugarbush a ratio of post- to pre-treatment sap yields, analogous to the growth-ratios for fiber crops, is a means of successfully overcoming tree-to-tree variability. In view of the methodological difficulties associated with the use of large trees, one is tempted to ask if a greenhouse approach with juvenile seedlings has possibilities. In such an approach, some more readily measurable tissue characteristic might be used as an indicator of subsequent sap yield and sugar content to elicit promising fertilizer schedules more speedily.

The review papers concerned with the rehabilitation of spoil banks (Czapowskyj) and urban and recreational sites (Richards & Leonard) elegantly demonstrate how valuable an aid fertilization can be for the enhancement of the environment. Each area is a complex field in itself, with individual situations within

each calling, in turn, for individual consideration. Greenhouse pot-trials are clearly of considerable value for the spoil-bank situation, and in addition there is scope for much field experimentation with combinations of fertilizer, tree seedlings, and N-fixing lesser vegetation. The importance of rehabilitation measures in urban recreational areas is emphasized by the observation that in heavily pressured parks a rotational cycle of use and rehabilitation has to be operated. Of particular interest are the pollution/nutritional relationships discussed, for they illustrate how carefully nutritional regimes may have to be tailored to prevent certain flora from being eliminated.

Of similar significance to the environment is Gagnon's review of the scale of sewage and town-waste production and the scope fertilizers derived from such potential pollutants have. In our increasingly industrialized society it is evident that greater amounts of such waste products will make their début as possible fertilizer materials. A valuable service will be rendered to society, no less to forestry, if we are able to indicate which of such materials can be used successfully in forestry.

Diagnostic procedures to assess fertilizer requirement can be regarded as the slowly developing theoretical basis for all fertilizer practice. Mader's comprehensive treatment constitutes a veritable *ade-mecum* on the topic. The emphasis given to correctly assessing inherent site potential cannot be exaggerated, for many fertilizer trials have been incorrectly located through ignoring this aspect. I believe that more data about critical foliar levels for conifers in the Northeast are available than is suggested. For example, I know that soil-nutrient levels correlate well with peatland productivities in Newfoundland. But aside from minor qualifications, it is salutary to note that after a most critical analysis of foliar and soil diagnostic aids, the

reliable and recommended procedure is still the well-designed field trial.

The proposal for a cooperative network of logically sited and well-designed trials deserves careful study. Yet many of the agencies that would be expected to participate have initiated a substantial number of trials. In eastern Canada, for example, there are well over 160 major field installations concerned with adult forest to be maintained during the next 5 to 10 years. The difficulty of finding areas of homogeneous forest large enough for new trials is turning researchers' attention to the possibilities of smaller single-tree plot designs.

In the discussion concerned with the evaluation of growth responses, one wonders whether the situations in the Northeast where fertilization is being tested to secure dominance and diameter-growth in overdense stands call for special assessment techniques. In the more detailed treatment of foliar and soil diagnostic procedures (Armson), one is compelled to question the progress and utility of the multiple-regression approach compared with critical foliar-levels. The papers cited are from the mid-1950s and, although relationships were statistically significant, their predictive value for another area of the same soil type was not corroborated.

Although the difficulties and limitations of the diagnostic procedures were discussed critically, I do not believe that all soil procedures "must be arbitrary". To employ $N \text{ KCl}$ or $0.01 \text{ M CaCl}_2 \cdot 6\text{H}_2\text{O}$ to measure pH, for example, is obviously an attempt to replace arbitrariness by a more theoretically based approach—a process that achieves greater or less success in all scientific method.

Many of us have wondered how we might refine our tree growth-response criteria. The lucid contribution on wood-quality attributes of significance in pulping (Gladstone & Gray) should do much to permit the nutritionist to advance beyond a simple density determination.

Finally, two papers (Brett, Weetman & Hill) show how the traditional nutritional approach is broadening out to embrace environmental considerations.

In the first, we saw an attempt to avoid some of the inconsistencies of past field experimentation when inexplicable or contradictory responses were sometimes obtained. The program is clearly ambitious and calls for more resources than many agencies could allocate to one study. But the approach has merit and aspires to give a synoptic meaning to each discipline participating. One might take a pessimistic view and ask whether the modelling might prove as restricted in utility as the multiple-regression formulas in foliar analysis. Or one might speculate about how unconvincing a note many new ventures start on and about the undoubted successes that growth-simulation modelling is already having.

Although the second paper is restricted to adult forest, it too demonstrates the importance of focus. Almost no specialty could be excluded if one thinks of the effects that fertilization might have upon forest ecosystems. One supposes that rather than trying to measure everything, everywhere, and at once, a strict attention to priorities would identify, first, the forests of interest, then the components of the particular forest of major importance that require study through appropriate disciplines.

The same critical perspective is necessary in the energy discussion. Environmentalists will be heartened to know that even if 2 million acres of forest were fertilized annually in North America, this would add only 1 percent to the tonnage of N already being used. In fact, only about 20,000 acres of forest are now fertilized annually in Canada, accounting for a mere 0.01 percent of the overall tonnage of N used. The fuel required to generate this would amount to no more than one or two freight-train loads of coal! This more comprehensive way of

viewing relative demands on resources and the economics of production has been neglected.

The restricted uptake of applied N by trees must make many of us wonder, along with Auchmoody & Filip, whether some alternative method of application should be investigated. An important question that arises from the discussion of leaching losses from different N-sources is that, although urea may show least N losses, it is far more likely to disperse organic matter into the lower parts of the soil profile and eventually into the drainage waters. Is it possible that on balance the optimal N source might not yet be known? Except on outwash sands, N is identified as the most important single nutrient element, but not the nutrient most likely to give the maximum growth response: this is usually a N+P combination. Both papers ably reveal the types of studies in progress to ensure that fertilization does not harm the environment.

THE TASKS AHEAD

The rationale for the Symposium and for bringing nutritionists and environmentalists of the Northeast together stems from the more intensive use of the forest resource and environment in an increasingly populated and accessible land. It is important that the two groups continue to work together and become progressively more interrelated.

Nutritionists in all facets of forest fertilization in the Northeast are united by a common objective. They seek a reliable, economic, and environmentally safe technology.

For a variety of reasons—scarcity of expertise, cost of research, past suboptimal field experimentation, numbers and types of agencies involved, and the unpublished nature of field trials—a more collaborative and mutually informative system of working warrants development. It is possible that a representative working group

could study how this might be achieved and put forward proposals.

Our Symposium has brought to light much research and many field trials showing very encouraging growth responses to fertilization. Unfortunately, the extent of commercial fertilization has not been sharply quantified, but seems small. The reason for this imbalance needs investigating and, if possible, remedying.

The general smallness of commercial fertilization and the quite specific and different forest conditions where fertilization is currently of interest suggest that there is unlikely to be an early wholesale fertilization of vast forest areas. For the nutritionist, this calls for a sharp focusing-in on those specific forest conditions where socio-economic forces generate an interest in fertilization, rather than an approach that endeavors to embrace the entire ecological spectrum.

Forest situations that will receive increasing attention in the coming years are nurseries, sugarbush, Christmas trees, spoil banks, urban and recreational areas, and juvenile growth at establishment, as well as semimature and pre-harvest coniferous and hardwood forests.

Because of the large number of field trials already in existence that remain unreported in the scientific literature, there seems to be a special need not only to implement some type of simple information data-sheet that could describe the essentials of a trial and its ecological setting, but also to make more provision for critically analyzing and reviewing the distribution and results of such trials.

In spite of the obvious progress being made in the challenging task of developing reliable foliar and soil diagnostic

techniques, it is clear from several authoritative contributions that the well-designed field trial will remain the only reliable means of testing for nutrient requirement for quite a number of years.

If the results from field trials are to be analyzed economically, their designs must be appropriate. For both nutritional and economic reasons, experimental approaches should generate the optimum blend of nutrients and dosages in the eliminative manner successfully developed and applied in agriculture.

Scope is seen for pot trials, and it is expected that critical foliar-levels now being published will generate appreciable interest and testing towards refinement.

Following this Symposium, more interest can be expected in the effects of fertilization on wood quality, an important area that nutritionists have hitherto been unable to exploit adequately.

Numerous studies complementary to the field trial are necessary to ensure that fertilizer recipes are environmentally safe. Two important papers reveal the way fertilizers can react with nontarget components of the forest ecosystem and indicate the approaches and types of studies that could be conducted to develop an environmentally safe technology.

In view of the very positive growth responses to N and N+P combinations, it is expected that considerable activity will focus on fertilizer sources containing these nutrient elements, on the reactions such materials might undergo in the soil, and on the pathways and processes by which such applied elements are transported or immobilized within the ecosystem.

CRITIQUE: FOREST FERTILIZATION IMPACTS ON WATER AND THE ENVIRONMENT

by KENNETH G. REINHART, *Forest Hydrologist,
USDA Forest Service, Northeastern Forest
Experiment Station, Upper Darby, Pa.*

ABSTRACT. Forest fertilization can contribute in many ways to an improved environment. It can help restore denuded or overused areas, improve wildlife habitat, release forest land for nonproduct uses, and help to recycle waste products. Yet forest fertilization could have a negative impact on the environment. The problem most likely to be encountered is an increase in the N level in streams and lakes, possibly leading to eutrophication. An important safety factor here is the likelihood that only limited areas will be treated, and these infrequently.

IN HIS CRITIQUE of this Symposium, Dr. Rennie has covered general and nutritional aspects. I will present a few comments on the effects of forest fertilization on the environment.

In our region, fertilizers have not yet been applied as a regular forest-management practice. Thus we are in the unusual and fortunate position of considering environmental impacts at an appropriate early stage (Hornbeck & Pierce). We must not only give due weight to these impacts; we must also convince the public that we are doing so.

Fertilizer applications that might be made can be classified in two general ways: (1) applications for increasing timber production; and (2) applications for other purposes.

OTHER THAN TIMBER PRODUCTION

Where the objective is not timber production, it may be the revegetation of disturbed areas (Czapowskyj), improvement of wildlife habitat (Behrend), or protection or rehabilitation of recreation areas (Richards & Leonard). Revegetation of bare areas improves aesthetic, controls erosion, and protects streams from sediment. Fertilizers have already been used rather extensively for revegetating logging roads and strip-mine areas.

Enhanced awareness of environment concerns will lead to increased use of fertilizer for these purposes in the future. Improvements in wildlife habitat and recreation areas are other possible ben-

fits. These non-timber applications may have some adverse off-site effects, but considering particularly the limited areal extent of these practices, any detrimental effects should be minor.

FOR TIMBER PRODUCTION

In the near future, most fertilizer applications will probably be made to enhance timber growth. Of the 95 studies on fertilizing hardwoods reported to Auchmoody and Filip, 83 were oriented toward increasing forest growth rates. For environmental purposes we must consider side effects, both damaging and beneficial.

In assessing the potential problem, we should first consider the expected extent of fertilizer application. Several speakers (Safford, Hughes & Post, Ellis, Auchmoody & Filip) said that forest fertilization should not and will not be used indiscriminately on all timber-producing lands. Biological and economic considerations will limit the areal extent, intensity, and frequency of application. Thus, as compared to agricultural practice, use of fertilizer in the forest should have much less impact on the environment.

On the other hand, water in forest streams and lakes is now of relatively high quality, and even a relatively small input of nutrients may be damaging. As Werner suggests, though we can draw upon experience in agriculture, forest fertilization may be unique enough to require a separate analysis.

In any operation, there are side effects on nontarget species and on other aspects of the ecosystem. Side effects must be studied for two reasons: (1) to promote the understanding necessary to achieve the objective of improved tree growth; and (2) to avoid serious detrimental impacts on the environment.

Thus the man who wants to grow more and better trees for profit—as well as the

environmentalist—is concerned with determining and assessing side effects (Brett). The presentations in this Symposium are encouraging; I see no likelihood of operators throwing on the fertilizer to see what happens next.

Negative Side Effects

Some side effects of fertilizer use may have a negative impact on environment. These include: (1) increased nutrients in streams and lakes (Hornbeck & Pierce, Werner, Aubertin et al., Richards & Leonard); (2) increased organic inputs to streams (Werner); (3) decreased water yield (Hornbeck & Pierce, Aubertin et al.); (4) damage to nontarget species (Aubertin et al., Shigo, Weetman & Hill); and (5) air pollution (mentioned indirectly).

The increase of nutrient inputs to streams and lakes is likely to be the most controversial aspect of forest fertilization.

N promises to be the element of major concern, for two reasons: indications are that more N will be applied than any other nutrient; and the N compounds are more subject to leaching than the other candidates for use (Pierce & Hornbeck, Werner). The general absence of overland flow in the forest prevents nutrient loss into the stream through erosion.

The major problem is the increase of N, especially as nitrates, in streams. The question arises: will this reduce water quality to the point where it will no longer meet drinking-water standards? The studies cited in papers presented (Hornbeck & Pierce, Werner, Aubertin et al.) indicate fairly low levels of N in soil leachates and in streamflow, though comparison is difficult because of different modes of expression. The maximum stream values for N after fertilization of the Fernow watershed (Aubertin et al.) did exceed drinking-water standards. But this followed complete fertilization of the whole small drainage all at one time. Dilution in time and space will serve to re-

duce this concentration. From the data available, I believe that forest fertilization can be planned and conducted without raising levels of nitrate N above the current drinking-water standard (10 p.p.m.). If this allowable level is lowered—and such action is under discussion—further consideration might have to be given to this subject.

N inputs to groundwater would be much like those to streamflow and would not be likely to create a serious problem.

But what of stream and lake eutrophication? Will N inputs be large enough to cause trouble? Here we have a much more complicated problem than the one presented by drinking-water standards. And we have more unanswered questions. We have some data (Aubertin et al.), and we will be getting more about how fertilizing watersheds affects N levels. But to what extent is N limiting in dependent aquatic ecosystems, and how much eutrophication, if any, will result from a given increased input? I haven't seen answers to these questions. We may need case-by-case studies because the answers will vary with the chemical makeup and other characteristics of individual streams and lakes and their patterns of use.

In the Fernow experiment (Aubertin et al.), an amount equal to 18 percent (45 pounds per acre) of the N applied was lost to the stream in the first year. This is high, especially since the urea they used has been considered less subject to leaching than many other formulations. For both economic efficiency and environmental protection, there seems to be a real need for a form less soluble than the urea used there and for different methods or timing of application to reduce this discharge into the stream.

That fertilizer application can trigger the release of nutrients other than those applied cannot be neglected, though the problem does not appear to be a major one. In the Fernow experiment (Auber-

tin et al.), only N was applied; but some increase in Ca discharge into the stream was also measured.

Successful forest fertilization will augment organic-matter production and might increase the organic input to the stream (Werner). I don't think a moderate increase in growth will have any serious effect here, but we need to learn more about it.

Forest fertilization will decrease water yield (Hornbeck & Pierce), at least slightly. No measurable change was found in the Fernow experiment (Aubertin et al.). From this result and other experience, I expect that the effect of fertilization on water yield will be small, generally not noticeable, and not measurable. Where forest cover is being established on open land, fertilizers may speed the time when the forest's higher rate of water use is achieved. The same might be true after fertilizing a forest cover that initially was too sparse to occupy the site fully.

Forest fertilization may affect many nontarget species; it may kill understory vegetation in local areas (Aubertin et al.), depress mycorrhizae (Shigo), and change the absolute or relative numbers of various consumers and decomposers (Weetman & Hill). Generally these effects will be important only as they affect long-range fertility, water, aesthetics, or some such resource value. These side effects must be studied lest prescribed fertilizer practices fail in one respect or another and the reasons remain undiscovered until it is too late.

Air pollution was not specifically discussed, but the loss of applied N through ammonia volatilization was mentioned (Aubertin et al.). And there must certainly be some loss of material to the atmosphere during aerial application. There doesn't seem to be any serious problem here, but possible impact should be considered when planning and conducting fertilization practices.

Positive Side Effects

There are some side effects of fertilizer application for wood production that have positive environmental impacts. These include: (1) reducing land area needed for timber production (Aubertin et al.); (2) increased productivity of aquatic flora and fauna (Werner); (3) improved wildlife habitat (Behrend); and (4) recycling of problem materials (Gagnon).

In the long run, perhaps the most important of the desirable side effects of forest fertilization, along with other intensive practices, will be the production of needed wood supplies on a smaller land area (Aubertin et al.). This should release some lands for other purposes, or decrease the impact that withdrawals for other purposes would have on these supplies. This may be considered a continuation of the agricultural trend of the last century or more; more forest land is now available for a variety of uses because of high crop production on prime acres.

We have already labeled eutrophication a negative side effect. In some circumstances, increased nutrient levels in stream or lake water will have a beneficial effect by increasing aquatic productivity, including fish (Werner). Which happens when and where may require case-by-case studies and much more basic knowledge than we now have.

We have also mentioned the possibility of obtaining wildlife benefits by using fertilizers. But wildlife habitat—particularly the nutritional value of browse and forbage—may be improved by fertilization for timber production (Behrend). The extent of such improvement will probably be slight unless wildlife objectives are built into the design of the practice.

Waste products of our society—comprised from garbage, sewage sludge, and sewage effluent—may be applied to forest land (Gagnon). In setting objectives for these actions, the relative weight given to

the need for disposal of wastes and the desirability of increased tree growth will vary, but generally both objectives can be achieved in some measure. Properly conducted disposal of waste in this manner can help keep our environment clean, but care must be taken to avoid adverse effects. I'm sure all aspects of this combination of opportunity and problem are being discussed thoroughly at the Symposium on Recycling of Wastewater and Sludge being held at the Pennsylvania State University concurrently with our Symposium.

Weetman and Hill discussed energy use in fertilizer production. When materials like sewage effluent are used instead of commercial fertilizers, this problem disappears.

Other Side Effects

Fertilization may affect insect and disease control (Shigo). I was unable to list this as either positive or negative, because apparently the effect can be either. I can only repeat Shigo's admonition that we cannot afford to treat the subject lightly.

I am sure there are other effects of forest fertilization on water and the environment, but I hope that you will agree that this covers most of the important ones.

PLANNING AHEAD

We may someday expect a wide variety of practices applied in many different situations. The environmental responses will also vary widely. We need to learn a great deal more about these. Fertilization practices must be planned carefully in light of the specific conditions in and adjacent to the area to be treated. And the environmental effects of fertilizer applications should be monitored carefully, at least until we are in a better position to predict impacts.

This Symposium has been a good start, but much remains to be done. Stone, Mader, and others emphasized the need for regional collaboration and team-

work to improve our knowledge about forest fertilization. These recommendations should be heeded when considering environmental impacts as well as wood production.

■







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NON-GAME WILDLIFE RESEARCH IN MEGALOPOLIS: THE FOREST SERVICE PROGRAM

by Jack Ward Thomas
and Richard M. DeGraaf



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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

The Authors

JACK WARD THOMAS is Principal Research Wildlife Biologist and Project Leader for the Northeastern Forest Experiment Station's multidisciplinary environmental forestry research project at the University of Massachusetts, Amherst. He received his B.S. degree from Texas A&M University in 1957, an M.S. degree from West Virginia University in 1969—both in wildlife science—and is now a Ph.D. candidate in forestry (resource planning) at the University of Massachusetts. He has authored or co-authored approximately 65 articles in the general field of wildlife biology.

RICHARD M. DE GRAAF is Assistant Research Wildlife Biologist at the Northeastern Station's Amherst research unit. He received his B.S. degree from Rutgers University in 1965, an M.S. degree from the University of Massachusetts in 1971, and is now a Ph.D. candidate at that institution, all in wildlife biology. He has authored or co-authored six articles on general wildlife biology.

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NON-GAME WILDLIFE RESEARCH IN MEGALOPOLIS: THE FOREST SERVICE PROGRAM

Abstract

The management of city habitats for wildlife production for enjoyment in forms other than hunting will require extensive coordinated research to provide guidance for such efforts. A generalized framework for such research is suggested and thirteen research studies particularly suited to the Forest Service research unit at Amherst, Mass., are outlined.

THE PROFESSIONS of wildlife management and forestry have traditionally been concerned with land management in rural areas for producing game and timber. The growth of megalopolis and the concentration of our citizenry in cities have brought these professions face-to-face with a challenge. If these professions are to improve the environments of most Americans, they must become active where the action is—in and around the cities.

This problem analysis is a guide to the wildlife-research efforts of the USDA Forest Service as it seeks to aid in the management of today's human environment. In the words of Gifford Pinchot, we hope we are "breaking new ground."

THE PROBLEM

We are told that by the year 2000 some 75 percent of the nation's population will live and work in cities (*Crissey 1971*). The primary habitat or living space of those citizens will be the neighborhoods where they live and

the areas where they work and play (*Zivnuska 1971*).

At a time when the average person is more and more isolated from the natural world, there seems to be an increasing public longing for experience with wildlife. This can be seen in the increased TV, magazine, and newspaper concern with wildlife and wild places. Yet, even these vicarious contacts seem to be in the form of fantasy visits to areas of the world remote from man's cities.

When we return from those armchair contacts with wild things and survey our everyday habitat we mourn or—even worse—accept the loss of these contacts as a penalty of life in the cities. But, if we are perceptive enough, we might say along with George Bernard Shaw . . . "You see things as they are; and you ask 'Why?' But I dream things that never were: and I ask 'Why not?'"

Why not revitalize our everyday living space so that we can purposefully and deliberately share it with plants and animals? They provide the interaction with nature that can yield a wealth of pleasure along with the constant lesson that man's actions now determine

the present and future suitability of Space-ship Earth for wildlife, for man—indeed for life itself.

Should there be an effort to provide wildlife, literally and figuratively, in man's backyard? There are a number of reasons for saying "yes" (*Shomon 1970, Sinton 1971, Stainbrook 1968*). Wildlife can provide a direct means for understanding the underlying ecological principles expressed by Commoner (1971): "Everything is connected to everything else . . . There is no such thing as a free lunch." The animals and the vegetation that supports them are a source of pleasure—to see, to hear, to smell.

But perhaps the best reason of all is that many people seem to want wildlife in the cities because it somehow makes their lives more complete and enjoyable.

Our goal is to develop the needed knowledge about: just if and how wildlife is important in the metropolitan areas; how wildlife habitat can be manipulated to produce or attract desirable wildlife; what wildlife species are the most desirable. We want to develop management plans for various potential wildlife habitats, and to determine how wildlife and their habitats might be best used to give city dwellers a feel for and knowledge of how the natural world works.

THE GEOGRAPHICAL AREA OF CONCERN

We are concerned with wildlife research needed to enhance human environments in and around the Nation's cities, particularly in the megalopolitan areas of the Northeast.

Megalopolis consists of a series of metropolitan centers from Boston, Massachusetts, to Washington, D. C., surrounded by rural areas that supply resource services such as water, food, and recreation. This service area (5 percent of the Nation's land) extends from Canada to North Carolina, between the Appalachians and the Atlantic, and contains 26 percent of the Nation's population (*Gottman 1961*).

Pronounced changes in land use from rural to urban uses are occurring within this area, and a shift of 8,755,000 acres to urban land

use is expected in the period 1960-2020. Population has increased from 34.4 million in 1940 to 50 million in 1970 and is expected to reach 55.6 million by 1980, 69.5 million by 2,000, and 86.2 million by 2020 (*USDA 1970*).

Marked changes in the distribution of various land uses is expected in the North Atlantic Region in the period 1963-2020: decreases in cropland (15.2 to 6.0 percent) and pasture (6.3 to 2.6 percent); and increases in forest land (57.4 to 64.4 percent) and urbanized areas (6.0 to 14.3 percent) (*USDA 1970*).

These ongoing land changes are seen as a trend toward a visual image of trees and houses (*Zube et al. 1971*).

THE ROLE OF NATURAL RESOURCE MANAGEMENT PROFESSIONS IN URBAN AREAS

The Wildlife Biologist's Role in Urban Areas

The purpose of wildlife management is to satisfy human needs and desires. We subscribe to Eggeling's (1971) philosophy, that man does not conserve wildlife for altruistic reasons but for the pleasure that he derives from it.

Some 75 percent of all Americans will live in cities by 2000 (*Crissey 1971*). Obviously, if wildlife managers want to have an impact on the environment of the majority, that is where they must be active (*Clawson 1968a and Foster 1971*).

As some states move toward total urbanization (*Grossman 1965 and Clawson 1968b*), their wildlife agencies must evolve into a new socially useful role or decline in stature and vigor.

The Bureau of Sports Fisheries and Wildlife has begun to define its role in urban-oriented society. Its director (*Gottschalk 1968*) stated: "If our Bureau were to focus, as we have in the past, on the wide open spaces and neglect the people in the city, I believe it would find itself in a very questionable orientation with society."

Some states, notably New York (*Miller et al. 1971*) and California (*Leach 1969*) have

initiated planning toward broadening their programs to include urban areas and non-game wildlife. Wildlife and other environmental management in the city may be the only chance to give people any understanding of nature (*Cain 1968*).

MacMullan (1968) put it this way: "I am convinced that not only can wildlife continue to have meaning for the denizen of megalopolis, it must be a part of his basic ecological understanding."

A FRAMEWORK FOR NEW RESEARCH

We conceive the problem components to be human preferences, habitat, and wildlife-human interaction. This analysis is limited to management of wildlife for aesthetic enhancement of megalopolis. We did not consider control or human-wildlife conflict resolution, which is receiving adequate attention elsewhere (*McCabe et al. 1970*).

There appear to be two not mutually exclusive ways of selecting species for management consideration. The biologists can select the species, manage for them, and try to convince the public that this is what is wanted and needed. Or the public can select the species for attention.

It is one thing to be convinced that wildlife management for the enhancement of man's environment is desirable and quite another to find funds for such programs. We must know if and how much the public is willing to pay, both for management by individual property owners and for government (local, state, or federal) efforts to influence wildlife habitat.

The habitat requirements of any species must be known before more than rudimentary management can be done. Such studies should be made according to the priorities determined by the investigations on human preference.

Areas available for management should be evaluated and categorized according to their potential as habitat for wildlife. Habitat-management techniques must be developed, tested, and evaluated. The evaluation should include cost/benefit analysis, even though the benefits may be intangible.

The important sites where human-wildlife interactions occur should be identified. Such results can be used in conjunction with the results of studies on human preference, determination of habitat requirements and sites available to provide management at the appropriate places, and times to provide maximum human benefit.

Most of the literature we reviewed indicated that interaction between man and wildlife (excluding pests) is desirable. We should know: (1) why it is important; (2) how this importance is acquired; and (3) what there is in the man-animal-habitat matrix that can be managed to enhance the experience for man.

The techniques for increasing or enhancing these interactions should be devised and tested. This interaction is the pay-off for aesthetic wildlife management, in much the same way as the opportunity to harvest game is for traditional wildlife management.

GENERALIZED RESEARCH TOPICS

The general topics we believe important for research attention follow. The list is general in the sense that we make no suggestions as to who or how the research should be conducted. Specific studies appropriate to the Forest Service efforts are discussed later.

Human Preferences for Wildlife Species

1. Studies of the preferences of city residents for various species, numbers, and location of wildlife would be valuable in guiding research and management. These studies should include stratifications of the human population sample to include variables such as cultural background, income, residence, ability to travel, education, and geographical area of concern.
2. Techniques and potential sources of funding for management and research should be investigated. Existing and potential constituency groups for such programs should be identified, quantified, and qualif~

3. Investigations should be made into existing law, customs, and governmental organization from local to state to federal level, to determine where authority and responsibility lie for management and research.

Wildlife Habitat

4. Techniques for determination of the habitat requirements of various species selected for management must be adapted or designed and tested for urban environments. These techniques may borrow liberally from procedures developed for use in the more traditional rural settings. However, considerable imagination will be necessary to account for habitat diversity and the effect of high human density and attendant technology.
5. Habitat requirements for selected species must be determined as prerequisites to management. Such determinations should include public health implications of this management. These studies should consider the inter-relationships of habitat requirements; that is, given management for a particular species, what other species will be expected and how?
6. Plant materials suitable to meet the habitat requirements of various wildlife species must be evaluated. Much information exists on domestic and native plant material, but not in a form useful to wildlife managers, landscape architects, garden centers, and gardeners. These evaluations should cover food, nesting, and cover provisions. Particularly promising is the evaluation of wild plants for use in suburban or park areas. Such studies should emphasize aesthetic values, wildlife values, and techniques for transplanting or propagation.
7. Management techniques should be tested for effectiveness. Such information should be stratified by area size and use (city lot to large park), requirements for pre-existing large trees, time delay from instigation of management to results, and cost-effectiveness.

8. Available areas for management should be identified, cataloged, and rated in terms of area, importance, ownership or control, availability (spatial and temporal), and limitations on management activities. Such studies would be utilized in combination with the preference studies to direct priority research and management-technique development toward appropriate sites.

Human-Wildlife Interaction

9. Sites where interaction now occurs should be cataloged and ranked in terms of quantity and quality. To pinpoint sites for intensive research and management, such information would be utilized in conjunction with information on areas available for management, species preferences, and habitat requirements.
10. The interactions should be evaluated in terms of contributions to the welfare of man. These values, once identified and weighed, might be emphasized in management.
11. Techniques for increasing interaction should be developed. These techniques might include bringing the wildlife and the people to the same place at appropriate times. Tastefulness and subtlety, and knowledge of the wildlife and people, will be required to create satisfactory encounters. Quality and quantity of the species, wildlife and human, and the site itself will be involved.
12. Techniques and materials should be developed for the use of appropriate areas as wildlife education areas. The studies should include habitat and wildlife-management procedures and development of lesson plans and educational materials to guide teachers and students.

Research Cooperation with Other Disciplines

Solutions to these research problems will require contributions from scientists of other disciplines for optimal results. Table 1 shows

the suggested collaboration among the disciplines, the appropriate locale, and a priority for each area of research.

SPECIFIC STUDIES

The following studies are planned (some are now being conducted) by, or through, the Environmental Forestry Research Unit of the USDA Forest Service at Amherst, Massachusetts. These are specific responses to the generalized research areas. These studies do not fill all the research needs. Much additional research by other researchers and agencies will be required.

These studies were planned for a 5-year time frame. Table 2 shows the priorities among studies and scheduled starting dates. The studies are categorized according to the problem components stated above.

1. Human Preferences for Wildlife Species

a. *Study Title: "Preferences of Suburban Residents Concerning Wildlife—A Pilot Study"*

This effort will be an extensive pretesting of procedures, techniques, and questionnaires for determining city dwellers' (1) attitudes toward wildlife, (2) preferences among wildlife species, and (3) willingness to practice or pay for practice of wildlife management in the urban forest interface. This study, although it is a pilot for a larger study, should yield results on attitudes and preferences.

b. *Study Title: "Preferences of Urban-Suburban Residents Concerning Wildlife"*

This study will be the full-scale application of the approaches outlined under study 1a above and will be replicated among several large cities and suburbs of the northeastern United States. The results will be used to select non-game birds and mammals as subjects for research effort, and to determine the interest and base support for potential management effort.

2. Wildlife Habitat

a. *Study Title: "Identification of Important Habitat Variables for Street-Side Occurrence of Selected Songbirds in a Small Town—A Pilot Study"*

This effort will develop and test a multivariate approach to determining habitat requirements for songbirds. Important habitat variables will be identified and procedures streamlined for large-scale application of the technique, which should be usable for determining habitat requirements of most songbirds over a wide range of habitats. As a secondary result, computer programs will be developed for use in later replicated efforts. Resulting publications should provide descriptions of habitat requirements of 10 selected species in small New England towns. A study plan has been developed, and research is under way on the influence of an urban park on distribution of songbirds in adjacent neighborhoods, utilizing the techniques developed here.

b. *Study Title: "Identification of Important Habitat Variables for Street-Side Occurrence of Selected Songbirds"*

Utilizing the bird species preference ratings developed under studies 1a and 1b, habitat requirements will be developed for 10 species per year for 3 years in each of 3 separate cases. Techniques and computer programs developed under study 2a will be utilized. Contract research for one or two of the replications may be desirable.

c. *Study Title: "Evaluation of Wild Shrubs for Possible Use in Habitat Management for Suburban Songbirds"*

Demands for habitat management for songbirds in suburbs might be met this way; and information on appropriate shrubs, their characteristics, and techniques for establishment would be useful. The objectives include: (1) selection and evaluation of 10 wild shrubs and (2) development of knowledge for selection of appropriate species to suit site requirements.

Methods will include: (1) selection of candidate species from literature review, using

Table I.—Res

Generalized research topics for wildlife research	Potential co					
	Economics	Law	Psychology	Sociology	Government	Geography
1. Preferences of urban residents for wildlife species	.	.	X	.	.	.
2. Identification of funding and revenue sources & constituencies	X	.	.	.	X	.
3. Assignment of research and management responsibilities	.	X	.	X	X	.
4. Technique development for study of habitat requirements in cities	.	.	.	.	.	.
5. Habitat requirements of wildlife species selected for management	.	.	.	.	.	.
6. Evaluation and development of plant materials for use in wildlife management in urban situations	.	.	.	.	.	.
7. Development and testing of wildlife habitat management techniques	X	.	.	.	.	.
8. Identification, cataloging, & rating of areas available for wildlife management practices	.	X	.	X	.	X
9. Cataloging & ranking of areas where significant human-wildlife interactions now occur	.	.	X	.	.	X
10. Evaluation of the significance of human-wildlife interaction	.	.	X	X	.	.
11. Development and testing of techniques for creating satisfactory human-wildlife interaction	X	.	X	X	.	.
12. Development and testing of appropriate techniques to use wildlife in teaching	.	.	.	X	.	.

*Research topics are grouped into first, second, or third priority in reference to the logical sequence of a continuing process.

d priorities

Horticulture	Planning	General ecology	Education	Major geographic focus			Priority*	
				Urban	Fringe	Rural	Research sequence	Management needs
.	.	.	.	X	X	.	1	1
.	.	.	.	X	X	.	3	1
.	.	.	.	X	X	.	3	1
.	.	X	.	X	X	.	1	2
.	.	X	.	X	X	X	2	2
X	.	X	.	.	X	X	2	3
.	.	X	.	.	X	X	2	2
.	.	X	.	.	X	X	.	1
.	.	X	.	.	X	X	.	1
.	.	.	.	X	X	.	2	3
.	.	X	.	.	X	X	.	3
.	.	.	.	X	X	X	.	3

in reference to the satisfaction of existing management needs.

Table 2.—Priorities among proposed studies and scheduled starting dates

Study No.	Name of study	Depends on completion of these studies for inception	Priority rating			Proposed beginning & ending dates
			1	2	3	
1a	Preferences of suburban residents concerning wildlife	..	X	..	..	Sept. 1973 Sept. 1974
1b	Preferences of urban-suburban residents concerning wildlife	1a	..	X	..	Jan. 1975 Jan. 1976
2a	Identification of important habitat variables for street-side occurrence of selected songbirds in a small town—a pilot study	..	X	..	..	May 1971 June 1973
2b	Identification of important habitat variables for street-side occurrence of selected songbirds in suburban areas of the northeastern United States	1a, 1b, 2a	..	X	..	May 1973 Sept. 1975
2c	Evaluation of wild shrubs for possible use in habitat management for suburban songbirds	..	..	..	X	May 1971 Oct. 1974
2d	Nest-site preferences of arboreal nesting songbirds in New England suburbs	2a	..	..	X	Aug. 1971 Sept. 1973
2e	Nest-site preferences of arboreal nesting songbirds in suburban areas of the northeastern United States	1a, 1b, 2a, 2b	..	..	X	Sept. 1973
2f	Bioassay of the value of wild shrubs developed for use in habitat management for suburban songbirds	2c	..	..	X	May 1973 Aug. 1975
2g	Evaluation of 20 years of change in the human environment in Massachusetts, 1955-1971	..	X	..	..	Jan. 1971
3a	Identification & preliminary evaluation of open space areas within or adjacent to cities that might provide wildlife habitat & human-wildlife interaction	2g	..	X	..	May 1971 Aug. 1974
3b	The evaluation & recommendations for management of cemeteries as open space areas providing wildlife habitat & human-wildlife interaction	..	..	..	X	Jan. 1972 June 1973
3c	Evaluation of techniques for increasing desirable human-wildlife contact in public & other heavily utilized areas	..	..	..	X	Sept. 1974 Aug. 1976
3d	Utilization of urban wildlife for educational purposes	3a, 3b	..	..	X	Sept. 1974 Sept. 1976

fruit production, range, attractiveness of growth form, and propagation probabilities as criteria; (2) propagation of shrubs; (3) out-plantings will be tested in natural and amended soils in Coastal Plain and Piedmont soils; (4) phenology of vital characters will be developed; (5) plants will be evaluated on aesthetic characteristics; and (6) recommendations on utilization of the shrubs will be derived. A study plan for this has been developed.

d. *Study Title:* "Nest-Site Preferences of Arboreal Nesting Songbirds in New England Suburbs"

Data collected under study 2a will be utilized. Nesting habitat is critical in any management plan, and such knowledge on preferred nest-sites in relation to available vegetation is lacking. The objectives are: (1) to identify suitable nest-sites, by bird species; (2) to develop a technique for determination of preferred nesting sites by occupied vertical nesting zones and the rating of plant species for this purpose.

Methods will include: (1) search for nests within vegetative study plots; (2) determine the occupied vertical nesting zone for each bird species; (3) examine location to determine randomness; and (4) assign index ratings to species as nest-sites. These techniques, once developed, can be utilized with the habitat-requirement determinations in study 2a. In that sense, this may also be considered a pilot study.

e. *Study Title:* "Nest-Site Preferences of Arboreal Nesting Songbirds in Suburban Areas of the northeastern United States"

This study will be conducted in conjunction with study 2b. The procedures, objectives, and anticipated results will be as described under study 2d. This is the application of the developed techniques to the problem. At least parts of this study will be cooperative aid or contract research.

f. *Study Title:* "Bioassay of the Value of Wild Shrubs Developed for Use in Habitat Management for Suburban Songbirds"

In this study we assume that there will be usable results from study 2c, which is concerned with selection and testing of candidate species from the horticultural and botanical standpoint. The selected species will be evaluated as to fruit production, contribution to bird food supply in terms of volume and nutrient value, and birds attracted.

g. *Study Title:* "Evaluation of 20 Years of Change in the Human Environment in Massachusetts, 1951-1971"

The objectives are to determine or provide: (1) changes in forest use over a 20-year period; (2) predictions of future rates and patterns of change; (3) vegetative and land-use maps; (4) visual-aesthetic criteria for describing scenic quality; (5) data banks in computerized form on past, present, and future land use; and (6) patterns and mechanisms of urban growth and decay on forested land.

Data will be obtained and analyzed as follows: (1) acquire 1971 aerial photography; (2) interpret photos by an appropriately categorized system; (3) compile statistical summaries, by town and county; (4) make predictions of future change based on past change, population shift, highway construction, and other factors; and (5) interpret change as related to demographic, socio-economic, and ecological factors. In addition to the direct results anticipated, other sub-studies may be instituted on the same base photography by the available interpreters. The study will provide base-line information on wildlife habitat—past, present, and future—that will be useful in planning efforts, particularly for the next study.

3. Human-Wildlife Interaction

a. *Study Title: "Identification and Preliminary Evaluation of Open Space Areas Within or Adjacent to Cities That Might Provide Wildlife Habitat and Human-Wildlife Interaction"*

From the aerial photography available from study 2g, open space areas that are available to the public but have not been traditionally managed for wildlife will be identified. Cemeteries and abandoned rights-of-way will be encountered (*Whyte 1968*). The sample will include several cities within Massachusetts. The techniques will include: (1) aerial photo interpretation; (2) ground verification; (3) categorization of open space encountered by type, availability, amount, and potential for the purposes mentioned; and (4) priority ranking of these areas as to potential and research priority (table 1).

b. *Study Title: "The Evaluation and Recommendations for Management of Cemeteries as Open Space Areas Providing Wildlife Habitat and Human-Wildlife Interaction"*

We assume that cemeteries will be selected as high-priority areas under the criteria of study 2h. The cemeteries will be categorized by vegetative composition, types of management, present rating as wildlife habitat, present use by people seeking wildlife-human interaction, and development of management recommendations for wildlife habitat and for increasing human-wildlife interaction. A study plan has been prepared for this research.

c. *Study Title: "Evaluation of Techniques for Increasing Desirable Human-Wildlife Contact in Public and Other Heavily Utilized Areas"*

This study will examine the effects of standard techniques such as scheduled feeding and use of nest boxes, for squirrels and birds in

selected public areas. The management will aim directly at increasing human-wildlife interaction, and indirectly at increasing wildlife populations. The study will determine the increase in interaction, evaluate wildlife response, evaluate human response, and develop cost/benefit ratios for increased interaction or increased wildlife, or both.

d. *Study Title: "Utilization of Urban Wildlife for Educational Purposes"*

This study will be aimed at development of management procedures for the areas identified under study 3a that would enhance their usefulness for demonstration or study areas for educational purposes. Also included will be development of a series of lesson plans and attendant educational materials (films, booklets, keys, etc.) for use by teachers and students. Cemeteries, studied under 3b, would be a potential area to use as a pilot.

CLOSING COMMENTS

We consider this analysis to be a starting point for our research and in no way feel that it represents the final word on such endeavors. Pilot studies may prove routes of inquiry unfruitful, new ideas may emerge as experience accumulates, and new directions may be taken. These efforts in wildlife research for increased human pleasure in our cities are only a part of the thrust in environmental forestry—a thrust that is necessary if we are to counteract the forces poignantly expressed by Wesley Le Faivre (1969):

"... How far, indeed the woods seem now.
How far indeed are they.
How distanst are the sullen caves;
the brooks and foot-paths lay
beneath a cold and concrete cloak;
the ponds of yesterday . . .
polluted far beyond reclaim.
And children cannot play
in woods that are no longer there . . .
in woods too far away."

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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

By Stanley M. Filip

Cutting and Cultural Methods for Managing Northern Hardwoods in the Northeastern United States



USDA FOREST SERVICE GENERAL TECHNICAL REPORT NE-5
1973

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

THE AUTHOR

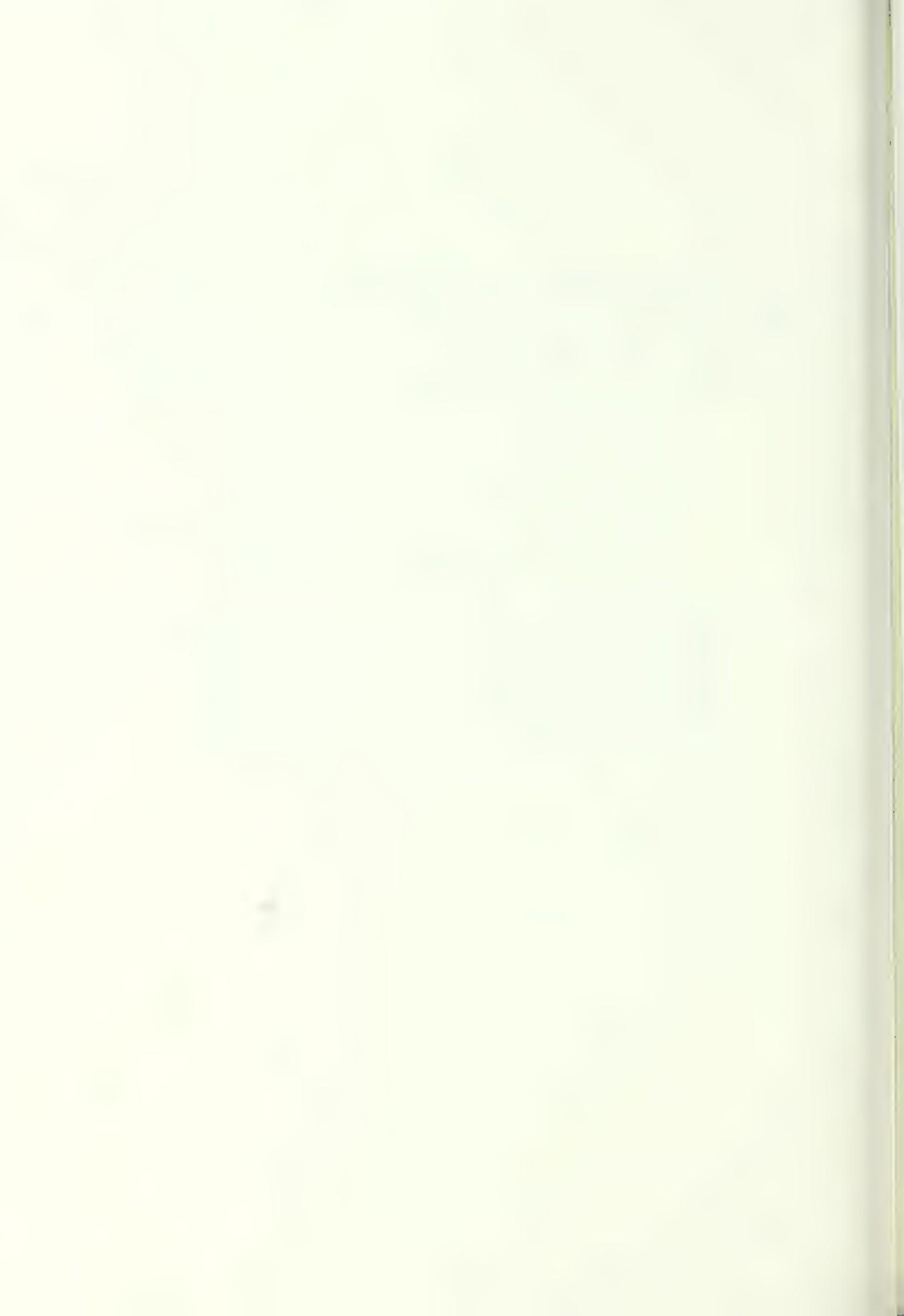
STANLEY M. FILIP, silviculturist, received his forestry training at The Pennsylvania State University. After working several years in consulting, industrial, and state forestry, he joined the Northeastern Forest Experiment Station of the USDA Forest Service as a research forester in 1946. Most of his research work has been in ecology, silviculture and management of northern hardwood forests in the Northeast. He is now on the staff of the Experiment Station's Forestry Sciences Laboratory at Durham, New Hampshire.

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Cutting and Cultural Methods for Managing Northern Hardwoods in the Northeastern United States

ABSTRACT

The steady increase in multiple use of northern hardwood forests in the Northeast makes it urgent for managers to keep selected stands highly productive. Maintaining a balanced structure by selection cutting is advisable for sugar maple and other shade-tolerant species. Stand harvesting in small blocks, strips, or patches works well for the highly valued yellow birch, paper birch, and white ash. Although the accepted cultural methods such as seedbed preparation, thinning, and improvement operations are helpful, new cultural methods must be developed to increase yields and shorten rotations.



NORTHERN HARDWOODS cover nearly 15 million acres (6.1 million hectares) or 35 percent of the commercial land area in the Northeastern United States — New Hampshire, Vermont, Maine, Massachusetts, and New York. These forests have always been important to many communities because they produce millions of cubic meters of timber each year, support a thriving summer and winter recreation trade, and provide a protective cover on the watersheds of public water supplies. The northern hardwood forest ecosystem also provides an excellent habitat for a variety of game animals and other wildlife.

Because many parts of the region in recent years have become readily accessible to people from large metropolitan areas by the expansion of highway and road systems, multiple use of northern hardwood forests is steadily increasing. Thus the productivity of northern hardwoods is of vital importance to the economy and welfare of the region. When stands are maintained in the most productive condition — stocked with desirable species, growing rapidly, and cut properly — most of the desired goods and services can be fully realized.

An important mission of our silvicultural research in the Northeast has been to develop alternative cutting and cultural methods for keeping northern hardwoods productive.

EXPERIMENTAL PROGRAM

Knowledge of managing northern hardwoods in the Northeast has been appreciably strengthened by basic and applied studies conducted by several federal, state, and university scientists. Many of the applied silvicultural studies have been conducted at the Bartlett Experimental Forest, located on the White Mountain National Forest in northern

New Hampshire. The soils and vegetation on this 2,600-acre (1,052-hectare) forest ecosystem are fairly representative of many of the northern hardwood sites found not only in New Hampshire, but also in the other northeastern states.

The Experimental Forest is managed by the research project on silviculture and management of northern hardwoods, headquartered at the Northeastern Forest Experiment Station's laboratory in Durham, New Hampshire.

MANAGEMENT DECISIONS

Sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), and American beech (*Fagus grandifolia* Ehrh.) are the primary timber species in the northern hardwood forests. Associated species are numerous; the more important ones are paper birch (*Betula papyrifera* Marsh.), white ash (*Fraxinus americana* L.), red maple (*Acer rubrum* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and red spruce (*Picea rubens* Sarg.).

Although markets have been developed for practically all northern hardwood species, only sugar maple, yellow birch, paper birch, and white ash tend to command comparatively high stumpage and log prices. This has been the market situation for many years, and it probably will remain unchanged for many more years. Industry demands for top-grade logs of these four species often exceed the supply.

In developing a management program, a timberland owner must first decide whether he wants his growing stock to yield top-grade products such as veneer logs, sawlogs, and millwood or to yield mostly pulpwood and other bulk products. A second basic decision he must make is whether to manage for a

high proportion of shade-tolerant species, intermediates, or intolerants. This would have a controlling influence over the silvicultural system he may use.

CUTTING AND CULTURAL METHODS

For Shade-Tolerant Species

Uneven-aged management implemented through selection cutting of individual trees or the harvesting of trees in groups of two or three is recommended for growing a high proportion of shade-tolerant species—sugar maple, beech, hemlock, and spruce (*Leak et al. 1969, Tubbs 1968*). Selection cutting will produce veneer logs, sawlogs, and millwood, with pulpwood as a byproduct.

To achieve maximum yields, the cuttings are repeated at 10- to 20-year intervals. Likewise, a deliberate attempt is made to mark trees for cutting in all diameter classes to develop and maintain a balanced stand structure. Residual basal area after cutting is usually 70 to 80 square feet per acre (16.1 to 18.4 square meters per hectare) in trees over 6 inches (15 centimeters) in diameter breast high (1.4 meters). However, no cutting should remove more than about 40 square feet per acre (9.2 square meters per hectare).

Distribution of numbers of trees and basal area for a typical stand at 80 square feet per acre (18.4 square meters per hectare) is:

D. b. h. (in)	class (cm)	Trees		Basal area—	
		Per acre	Per hectare	Per acre	Per hectare
6-10	15-25	60	148	20	4.6
12-16	30-41	30	74	28	6.4
18+	46+	15	37	32	7.4
	Total	105	259	80	18.4

In many of today's uneven-aged stands, preferences for particular species in past cutting operations and heavy mortality or deterioration from disease attacks in some species (such as beech) have caused considerable variation in structure, stocking, composition, and grade. It may take three or more cyclic cuts to improve the productivity of such

stands. Yields from improvement cuttings may run 55 percent or higher in low-value products (*Filip 1967*). In subsequent cuttings, the yield should be mostly top-grade products.

To accomplish some of the needed cultural work, cull trees can be marked for optional removal by the logging operator. However, the trend is to have the sale contract require that the operator cut such trees, with an allowance on the stumpage for this work.

Often additional cultural work is needed in unmerchantable size classes to improve species composition—especially to reduce the overabundance of beech in favor of the higher-value sugar maple. Removing trees down to 2 inches (5 centimeters) in diameter breast high (d.b.h.) may be necessary.

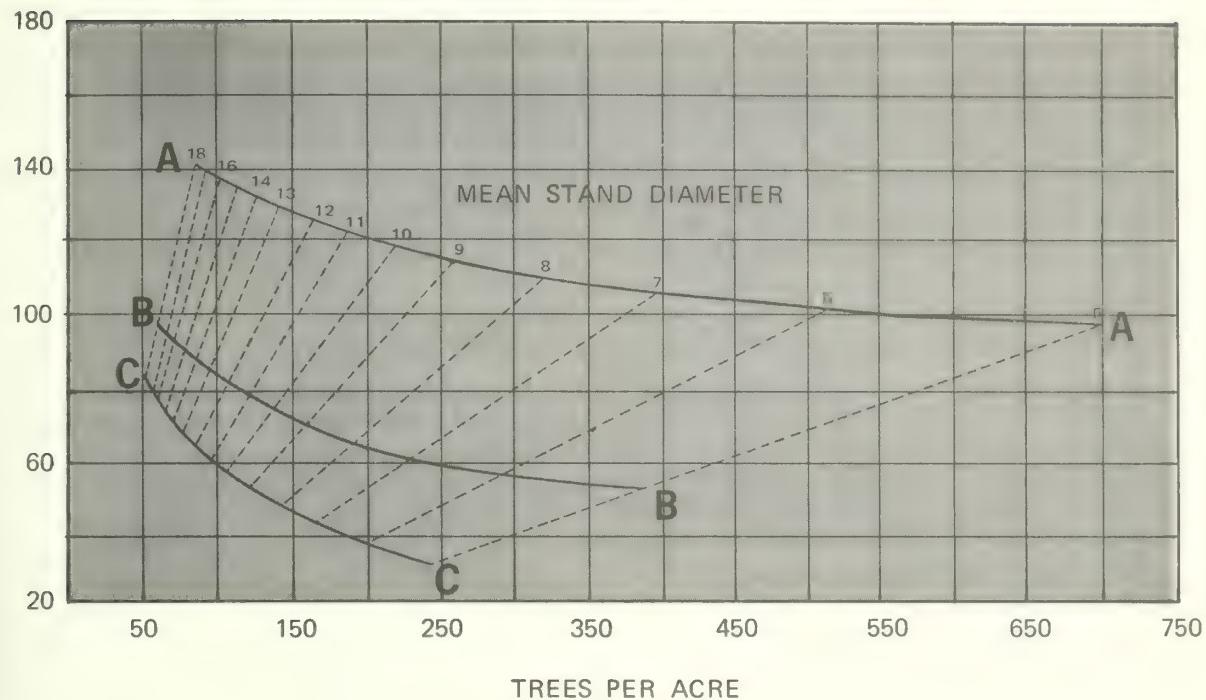
Aesthetically, the public generally accepts selection cutting because a residual stand always covers the site and disturbance from logging is not so apparent. Selection cutting now appears to be an important silvicultural option where multiple objectives must be considered, as on publicly owned timberlands.

For Species Intermediate or Intolerant of Shade

Even-aged management is recommended for growing a high proportion of intermediate and intolerant northern hardwoods. The commercially important species included here are yellow birch (intermediate), white ash (intermediate), and paper birch (intolerant). When used appropriately, even-aged management will produce top-grade products. The system is also well suited for pulpwood production, particularly in view of the trend toward greater mechanization in the woods.

Recently, we developed a stocking chart to help a manager determine when thinnings and harvest cuttings should be made in even-aged stands (fig. 1). The chart is based on number of trees per acre in the main canopy, average d.b.h. in inches, and basal area in square feet per acre. Three levels of stocking are defined: A, B, and C. Stands above the A-level are overstocked. Stands between A- and B-level are adequately stocked. Stands between B- and C-level should be adequately stocked in 10 years. Stands below the C-level

Figure 1.—Stocking chart for even-aged northern hardwoods.



are understocked. Thinning may be considered when stocking is at least midway between the B- and A-levels.

Where high proportions of the birches are to be naturally regenerated, special attention must be given to cutting and cultural methods. Generally some form of complete stand removal for the final or harvest cutting—and seedbed preparation—are needed for successful stand establishment. Optimum conditions for regenerating white ash have not been determined experimentally. However, the conditions that are favorable for yellow birch tend to be favorable for white ash.

Complete stand removal can be done in patches, strips, or blocks. In each case, the harvesting of merchantable trees is followed by mechanical or chemical removal of all unmerchantable trees down to 2 inches (5 centimeters) in d.b.h. Frequently, the harvesting and follow-up cultural treatment are done as two separate operations. However, in some stands it may be more efficient and less costly to contract with the logging operator to fell the unmerchantable trees during logging.

Patches range from 0.1 to 0.75 acre (0.04

to 0.3 hectare) in size. Although patch cuttings encourage the regeneration of both birches, they are difficult to lay out and impractical to handle when the entire area is to be systematically covered over a period of years. However, patches are appropriate when used in combination with selection cutting under uneven-aged management. Groups of mature, overmature, or defective trees are used as nuclei for the patches (*Gilbert and Jensen 1958*).

Strip cutting equals patch cutting silviculturally, but is more feasible to apply. Strips are particularly favorable for regenerating yellow birch (ratio as high as 10 yellow birch to 1 paper birch). Strips can be 50 to 100 feet (15 to 30 meters) wide; but for best yellow birch regeneration, they should be about 50 feet (15 meters) wide and oriented in an east-west direction. In practice, the strips are cut in groups in progressive order, so that every third or fourth strip is cut simultaneously on the south edge of the previous strip. The progressive cutting provides sunlight for the established seedlings while at the same time it creates a heavily shaded

new strip where new seedlings can become established.

Block cutting is more favorable for regenerating paper birch than yellow birch. This cutting method will result in regeneration composed roughly of two-fifths intolerants, one-fifth intermediates, and two-fifths tolerants (*Leak and Wilson 1958*). To insure prompt and adequate natural birch regeneration, a seed source must be available. The adjacent stand can provide the seed source in block cuttings up to 10 acres (4 hectares). For larger blocks, the cutting should be done between September and April during a good seed year to take advantage of the seed from harvested trees. Otherwise, leaving seed trees would be necessary. According to our experience, birch seeds usually do not remain viable beyond the first growing season.

Birch regenerates best on disturbed seedbeds where mineral soil is partially exposed or mixed with humus (*Barrett et al. 1962, Marquis 1965, Filip 1969*). If about 50 percent of the soil surface is not disturbed during the logging operation, additional roughing-up or scarification should be considered. Scarification of 50 percent of the surface area with a large tractor and root rake (toothed blade) will require about 1.3 hours per acre (3.2 hours per hectare) (*Filip and Shirley 1968*). Seedbed preparation with power equipment not only provides the desired mineral soil-humus mixture, but also removes much unwanted vegetation that often suppresses newly-established birch seedlings.

The public tends to resent even-aged harvesting, especially when the openings are readily visible from main roads or roadside vistas. The unsightliness of logging slash and snags resulting from after-logging cultural work causes much of this resentment. The

aesthetic problem can be minimized in several ways: utilizing all material possible from the harvesting operation, leaving an uncut strip adjacent to roads, felling all unmerchantable stems, restricting the size of cutting, making irregular cutting boundaries to blend with the landscape, removing some of the slash, cutting up slash so that it will lay close to the ground, and fertilizing the cut-over area to stimulate the height growth of regeneration.

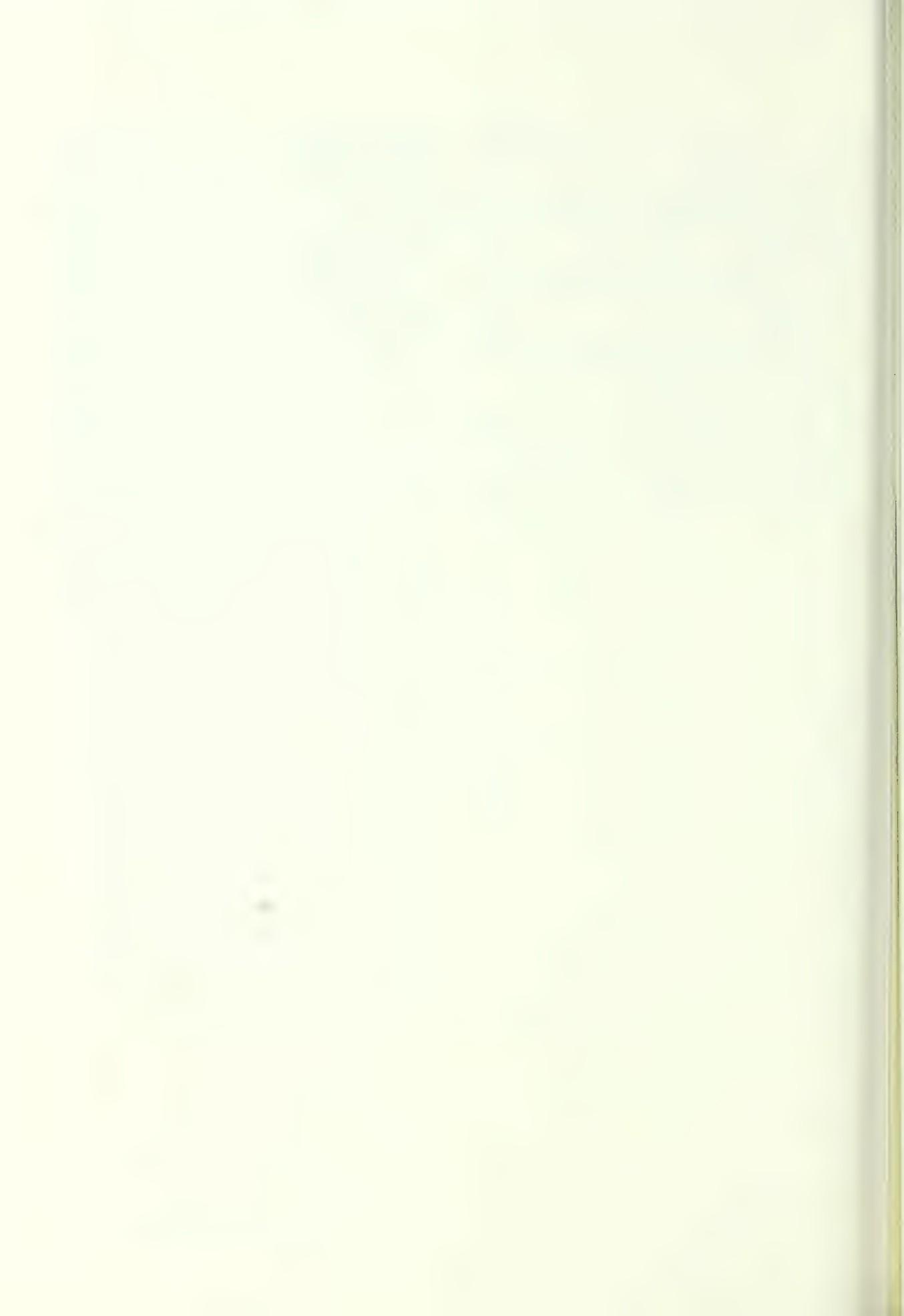
RESEARCH NEEDED

In the Northeast, probably more than elsewhere in the United States, heavy recreational and aesthetic pressures are forcing the withdrawal of land from timber production or restricting such use. Coupled with these pressures is the ever-increasing cost of owning timberland. Foresters are faced with the inevitable problem of growing more and better timber on less land. It is imperative that new cultural methods for shortening rotations and increasing timberland productivity be developed. Of several alternatives, forest fertilization offers considerable promise.

Laboratory and greenhouse studies have shown that yellow birch seedlings, in particular, respond appreciably in height and weight growth from additions of nitrogen, phosphorus, and dolomitic limestone to northern hardwood subsoils (*Hoyle 1969*). In field tests, broadcast applications of limestone and fertilizer after complete stand removal and scarification increased average height growth of free-to-grow paper birch seedlings by 55 percent in two growing seasons. These results are encouraging. However, more research is needed to determine the full range of growth responses that are possible with fertilizers and to evaluate the cost-benefit ratios that may be expected under various circumstances.

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A Silvicultural Guide for **SPRUCE-FIR** *in the Northeast*

by Robert M. Frank
and John C. Bjorkbom

USDA FOREST SERVICE GENERAL TECHNICAL REPORT NE-6
1973

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

The Authors

ROBERT M. FRANK, research forester, received a bachelor of science degree in forestry from the Pennsylvania State University in 1954 and a master of forestry degree in forest products from the same university in 1956. He joined the USDA Forest Service in 1957 and has served in economics research, forest survey, and mine-spoil re-vegetation projects at the Northeastern Forest Experiment Station. Since 1963, he has been on the staff of the Station's spruce-fir silviculture project at Orono, Maine.

JOHN C. BJORKBOM received his forestry training at Pennsylvania State University. After working for several years in state and industrial forestry, he joined the Northeastern Forest Experiment Station in 1948. His research work has been with timber management of northern hardwoods and with the regeneration of paper birch in New Hampshire and Maine. He is now on the staff of the Station's Forestry Sciences Laboratory at Warren, Pennsylvania.

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A Silvicultural Guide for SPRUCE-FIR in the Northeast

ABSTRACT

A practical guide to the silvicultural treatment of spruce-fir stands for timber production in New England and New York. Both even-aged and uneven-aged management are considered, covering both the establishment of new stands and the culture of existing stands. Includes a set of prescriptions describing specific treatments for a range of stand conditions and management objectives.

ACKNOWLEDGMENT

Full recognition is made of the contributions of Arthur C. Hart in the initial preparation of the material contained in this guide. At the time of his death, Mr. Hart was in charge of the research program for spruce-fir silviculture in Orono, Maine.

A major portion of his professional career was spent in northern New England, where he was considered by many to be an expert in spruce-fir forestry. Many of his research findings and observations are contained in this guide. The process of preparing this publication was made easier because of his work.

The authors are proud to dedicate this publication to the memory of Arthur C. Hart.

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INTRODUCTION

THIS PUBLICATION was developed to answer the need for a silvicultural guide to the management of spruce-fir types in the spruce-fir region of northern New England and New York. Such types occupy 13.4 million acres of land, of which all but 5 percent are privately owned. This guide was designed not only to supplement professional knowledge, but also for the benefit of the many laymen who will find it informative.

The silviculture prescribed is based on achieving maximum production of timber of the desired species and size. This can be done by maintaining stands that fully use the growing capacity of the site, by regular timber-stand-improvement operations, by periodic harvests to achieve rapid growth, and by regeneration methods that will secure adequate re-

production quickly (fig. 1). The guide applies to sites that are reasonably capable of developing naturally into stands containing at least 50 percent of their basal area in spruce-fir. It is not designed for plantations, and caution is advised when applying this guide to pure upland red spruce stands or to pure stands of black spruce.

Silvicultural methods that are compatible with the many land uses other than timber production may require adjustment of the prescriptions in this guide. No general rules are possible because of the variety of circumstances that may be encountered. Each case must be considered individually.

The information contained in the guide is based on a review of literature, current research, consultation with forest managers, and observation. It is not the last word in silvicultural practice; the results of research now

Figure 1.—Spruce and balsam fir reproduction in a small opening in the stand, a common occurrence in the spruce-fir forest.



under way or being contemplated may require future modification.

Similar guides for the silvicultural management of paper birch may be found in USDA Forest Service Research Paper NE-130 (*Marquis et al. 1969*); guides for the silviculture of northern hardwoods may be found in USDA Forest Service Research Paper NE-143 (*Leak et al. 1969*).

SPRUCE-FIR TYPES AND SPECIES

Pure stands of spruce-fir occur on the poorly drained soils of swamps and flats adjacent to lakes and streams and on the thin soils of upper slopes. Above the flats, where the soils are deeper and better drained, the proportion of hardwood species is greater.

The spruces—red (*Picea rubens* Sarg.), white (*P. glauca* (Moench) Voss), and black (*P. mariana* (Mill.) B.S.P.)—and balsam fir (*Abies balsamea* (L.) Mill.) are the major components of the spruce-fir cover types in the Northeast. The important types include balsam fir, red spruce, red spruce—balsam fir, paper birch—red spruce—balsam fir, and white spruce—balsam fir—paper birch.

Other softwood species are also found in these forest types, principally eastern hemlock (*Tsuga canadensis* (L.) Carr.), eastern white pine (*Pinus strobus* L.), northern white cedar (*Thuja occidentalis* L.), and occasionally tamarack (*Larix laricina* (DuRoi) K. Koch). Associated hardwoods include sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), yellow birch (*Betula alleghaniensis* Britton), paper birch (*Betula papyrifera* Marsh.), American beech (*Fagus grandifolia* Ehrh.), poplar (*Populus* spp.) and ash (*Fraxinus* spp.).

Occurrence

In the Northeastern United States, the spruces and fir occur from the Canadian border through New England and New York. At the higher elevations in the mountain areas, red spruce occurs as far south as Tennessee and North Carolina, but white spruce extends only into New York. Balsam fir reaches into Virginia and West Virginia, and black spruce

reaches into Pennsylvania. The principal commercial range includes northern New England and New York.

The soils where spruce-fir grow are mostly acid podsols with a thick mor humus and a well-defined A₂ horizon—characteristics commonly associated with abundant rainfall, cool climate, and softwood cover. Many of the glacial till soils have a compact layer averaging 18 inches below the surface.

Pulpwood is the principal product of the spruce-fir region. More than two-thirds of the annual harvest of spruce and fir is for pulpwood, although sawlogs have a higher value per cubic foot.

Balsam fir and black spruce are generally grown to a maximum size of 10 to 12 inches d.b.h.; red and white spruce are grown as large as 14 to 16 inches for pulpwood and 18 to 20 inches for sawlogs.

Stand Establishment

The basic requirements for successful natural spruce-fir regeneration are: an adequate seed supply; proper seedbed; and light, temperature, and moisture conditions that are conducive to seed germination and seedling survival. Seed production may begin when trees are about 15 years old, but significant production usually does not begin until the trees are 25 to 30 years old or later. Very few viable seeds are stored in the forest floor for more than 1 year. Some of the silvical characteristics of the several species are given in table 2, appendix (*Fowell 1965*).

Mineral soil is an excellent seedbed for germination. Generally ample moisture is available, and soil temperatures are moderate. Litter and humus are poorer seedbeds because they are likely to be drier and hotter than mineral soil. Severe competition makes heavy sod the poorest seedbed.

Favorable seedling development is greatly affected by light, temperature, and moisture conditions. Initially the light requirements conducive to early establishment seem not to exceed 10 percent of full sunlight (*Vezina and Peck 1964*). But as the seedling develops, light intensities of 50 percent or more are necessary for optimum growth (*Shirley 1943*).

Soil surface temperatures between 115°F. and 130°F. result in the mortality of most young conifer seedlings even when they are exposed for very short periods of time (Baker 1929). Damage caused by late frost to leaders and new lateral growth is seldom severe.

Although seedlings of spruce and fir are similar in many respects, spruce is weaker and more fragile, and grows slower during the establishment period.

Seedlings that have obtained a height of about 6 inches can be considered as being established. Once a seedling becomes established, early growth is determined largely by the amount and character of overhead competition. Dense growth of bracken fern, raspberry, and hardwood sprouts are the chief competitors of seedlings on heavily cutover lands; but both balsam fir and the spruces will survive many years of suppression and still respond to release.

Site Classification

The shade tolerance of spruce and fir and the multiple-aged condition of the stands in which they normally occur make determination of site index difficult. In addition, spruce and fir do not have as wide a range in site index as do many other tree species that grow well on a wide variety of sites. For these reasons, site index as a method of site classification is not used in this guide. However, Meyer's (1929) site-index values for various stand types are illustrated below. The figures are based on the average height of dominant and codominant trees at 50 years:

Stand type	Site-index range
Primary softwood site:	
Spruce swamp	24 to 35
Spruce flat	27 to 39
Upper spruce slope	up to 35
Old farmland	31 to 44 or more
Secondary softwood site:	
Lower spruce slope	27 to 47
Old farmland	less than 39 to 50

Despite the wide variety of these sites, they can be placed in one of two general classes—primary softwood sites or secondary softwood sites (Westveld 1941). These classes are

meaningful in terms of potential stand composition, growth, and reproduction.

Primary softwood sites occur under conditions of poor or impeded drainage in the so-called spruce-fir swamps, flats, and other lower topographic positions. Spruce-fir—particularly red spruce—also is common on the thin soils of upper slopes. Characteristic shallow rooting on these soils makes open stands susceptible to windthrow. These sites are composed mostly of softwood species. Hardwoods comprise less than 25 percent of the stand and are mostly paper birch, yellow birch, aspen, red maple, and an occasional beech or sugar maple. Feather mosses, ferns, and numerous herbs make up the low ground vegetation characteristic of these sites.

Secondary softwood sites occur on the better-drained sites of higher topographic positions and on medium-elevation ridge lands. Hardwoods may comprise from 25 percent to as much as 70 percent of stands on these sites, often competing harshly with spruce-fir. However, the tolerant red spruce and balsam fir may become established in the understory, responding to release if the overstory is removed. On such sites, the hardwoods usually are beech, sugar maple, and yellow birch. Herbaceous vegetation is less common than shrubs such as witch hobble (*Viburnum alnifolium* Marsh.), striped maple (*Acer pensylvanicum* L.), and mountain maple (*Acer spicatum* Lam.).

Principal Damaging Agents

Many insects and diseases damage spruce and fir. However, spruce is relatively free from these destructive agents until it matures. Fir, at all ages, is more subject to insect and disease attack. Only the more important insects and diseases are mentioned here.

One of the most serious insects is the spruce budworm (*Choristoneura fumiferana* Clemens), a defoliator that attacks both spruce and fir, but prefers fir. Vast outbreaks of this insect in the past have killed millions of cords of pulpwood, primarily in stands containing mature and overmature fir.

The balsam woolly aphid (*Adelges piceae* Ratzeburg), which attacks fir, is an intro-

duced insect that seems to be becoming increasingly serious in the Northeast. The salivary injections of the aphid kill or deform fir trees.

Most silvicultural theories proposed to minimize the impact of insect outbreaks have not been put into practice on a scale large enough to test their effectiveness against epidemic populations. Some degree of success has been achieved with biological control and aerial spraying.

The important diseases of spruce include red ring rot (*Fomes pini*), which enters through dead branch stubs, and red brown butt rot (*Polyporus schweinitzii*), which enters largely through basal wounds. They are usually confined to overmature or damaged trees. Thus a stand that is maintained in a healthy, vigorous condition will be less susceptible to infection.

One fungus (*Stereum sanguinalentum* Fr.) causes over 90 percent of all trunk rot in living balsam fir trees. Often referred to as "red heart", this disease enters the tree through broken tops, broken branches, and other injuries.

Infections of balsam fir by other fungi cause various butt and root rots, which are not as serious as the trunk rot disease. However, these rots weaken the trees, making them susceptible to wind damage.

In stands where these diseases are serious, commercial thinning should begin when tree diameters are about 8 inches. But other timber-stand-improvement measures should be taken as soon as problems warrant immediate attention. The pathological rotation of fir is 50 to 60 years along coastal areas in Maine and near southern extremes in the spruce-fir region. In the interior and more northern areas, final harvest should take place at 70 to 90 years.

The frequency of occurrence of the various types of rot in balsam fir does not vary greatly between sites. However, the important trunk rots seem to be slightly more prevalent on primary softwood sites (Basham *et al.* 1953).

Spruce and fir are shallow-rooted. Most of the feeding roots are in the duff and the top few inches of mineral soil. Because of their shallow root systems, thin bark, and flammable needles, trees of all ages are easily killed

by fire. Their shallow root systems also make them subject to windfall. Caution is necessary in stands subjected to harvesting operations in areas where windfall is known to be a problem. Damage can be reduced by leaving uncut portions along the windward edges of the stand. Depth of these protective strips should be a minimum of one-half the height of the trees to be harvested.

Some injury and mortality of spruce and fir is caused by animals and birds. These pests include porcupine, bear, deer, hares, and yellow-bellied sapsuckers. However, there is little that can be done silviculturally to prevent this kind of damage.

MANAGEMENT OBJECTIVES

Traditionally, the major objective of timber management has been to grow the most of a given timber product that the land is capable of producing, either in the shortest time or at the least expense. And it is important to define a specific objective, because without a definite course of management, the full potential of the land cannot be realized. The four objectives that follow are framed to meet most needs although specific objectives may be quite different and require modification.

Objective 1.—Maximum production of spruce-fir pulpwood. In terms of this guide, objective 1 is stated for timberland owners who desire to grow only pulpwood.

Objective 2.—To produce a maximum proportion of spruce-fir veneer logs or sawlogs and a minimum proportion of pulpwood. In terms of this guide, objective 2 is stated for timberland owners who depend on others for markets and for sawmill and veneer mill owners who will usually want to grow sawlogs or veneer logs to supply their mills. If possible, these owners will usually market smaller trees from intermediate harvests or improvement operations as pulpwood. But the availability and reliability of markets will determine both the products and species toward which these owners slant their management.

Objective 3.—The maximum production of the highest value timber products of all spe-

cies present or adapted to the site. This objective is similar to objective 2, except that where markets are available for associated species of high value, management will be aimed at maximum returns from all species. However, in this guide, management of mixed species is limited to stands in which at least 50 percent of the basal area is spruce-fir. For many stands with less spruce-fir, the silvicultural guides for northern hardwoods or paper birch should be used.

The first three objectives are applicable when timber is the primary product. The fourth objective is necessary because other forest uses—recreation, water, wildlife, esthetics—may be considered primary products rather than byproducts of timber management. Although timber management is normally compatible, these uses of forest lands readily visible from tourist routes and scenic highways, in places adjacent to recreation areas, in roadside and waterside strips, and in watersheds, may well be considered the primary objective.

Objective 4.—Maximum production of the desired product other than timber, including recreation, water, wildlife, and esthetics by silvicultural methods that are compatible with some degree of timber production. To achieve objective 4, considerable adjustment of the prescriptions in this guide will usually be required, especially for even-aged silviculture. State service foresters or consulting foresters can be consulted for additional advice as specific cases are encountered.

SPECIES COMPOSITION GOALS

In stands where balsam fir is susceptible to insect and disease attack, the goal should be to decrease the proportion of fir in spruce-fir stands. This may be hard to do because fir tends to increase in proportion to spruce in second-growth stands. But foresters have been aware for years that the best way to achieve a better balance between spruce and fir is to reduce the amount of fir by harvesting it for pulpwood before it deteriorates. In general, spruce can be held in at least equal ratio to the less desirable fir only if a continuous forest

cover and sources of spruce seed are maintained. If the site is producing fast-growing, high-quality fir, then the decision to favor spruce is less absolute. Product objective now enters into the decision-making. And for some uses, fir may even be encouraged.

In spruce-fir stands where hemlock is a significant component, it may be desirable to favor hemlock over fir. Hemlock is less susceptible to insects and diseases and is longer-lived.

Unfavorable site conditions retard the growth of hardwoods more than they retard the growth of spruce and fir. Therefore, on primary softwood sites, spruce and fir should be favored over the hardwoods. On secondary softwood sites, the difference in growth is not so great. On these sites, the greater value of the hardwoods for veneer or sawlogs becomes an important factor; and it may be desirable to favor hardwoods over spruce and fir.

In the final analysis, the forester should work toward creating and maintaining the species composition that best meets the owner's objective within biological and economical limitations.

SILVICULTURAL SYSTEMS

Silvicultural systems for spruce-fir stands lead to either uneven-aged stands or to even-aged stands.

Uneven-aged stands are those in which the trees are of at least three distinct age classes irregularly mixed in the same area (*Society of American Foresters 1950*). Except for very old stands, uneven-aged stands are distinctly irregular in height; and there is great variation in tree size (fig. 2). These stands are developed or maintained by relatively frequent harvests made throughout the rotation. The distribution of diameters in a balanced uneven-aged stand will plot into a characteristically inverted J-shaped curve.

Even-aged stands are those in which the difference between the oldest and the youngest trees does not exceed 10 to 20 years or 25 percent of the length of the rotation. Trees in these stands tend to be rather uniform in height, but they frequently cover a wide range



Figure 2.—An unmanaged, uneven-aged spruce-fir stand with a large component of hemlock.

of diameter classes (fig. 3). These stands usually develop after the sudden removal of the previous stands through logging, fire, or other cause. A plotting of diameters will usually result in a curve resembling a bell-shaped form.

It is not always an easy task to decide whether or not a particular stand should be considered uneven-aged or even-aged. This is especially true for types of stands possessing only two age classes. This question is commonly answered when the forest manager considers the kind of management he intends to apply to the forest property. The age of the stand is ignored and its character is developed by the silvicultural method being used in the management of the property.

Uneven-aged Silviculture

The term selection system is applied to any silvicultural program aimed at the creation or maintenance of an uneven-aged stand and includes some form of periodic harvesting.

Because spruce and fir are usually able to regenerate and grow under overhead shade, truly uneven-aged stands will develop in areas not drastically disturbed by nature or man. Thus the selection method is well adapted to the management of a spruce-fir stand. The pe-

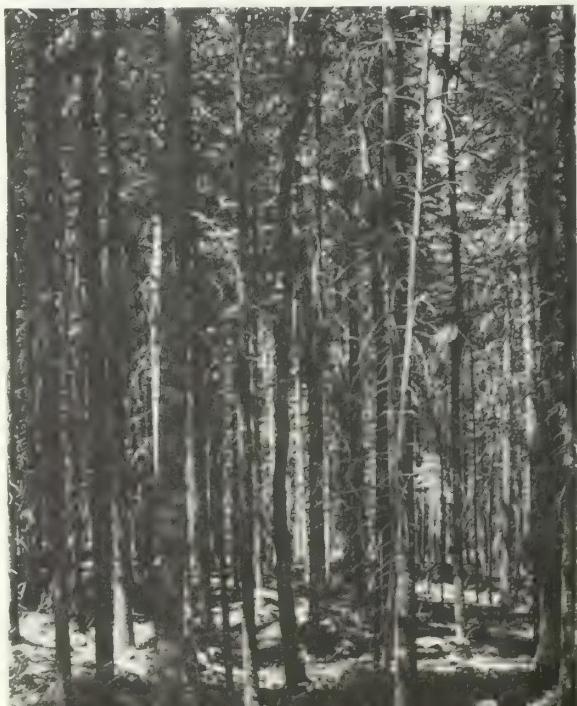
riodic harvests maintain a continuous forest cover, and the retention of spruce seed trees can favor the regeneration of this species. These harvests may also increase the proportion of spruce by removing the shorter-lived balsam fir.

Uneven-aged silviculture has other advantages. The growing space on each acre is more fully utilized in the vertical plane. The environmental conditions are more stable, and the plant and animal populations of the stand are more stable. Fire hazard from slash accumulations is less. In general, there is less chance of losing an entire stand at once through insect attack, infectious disease, or other natural catastrophe. And the area may appear more attractive to the esthetic-conscious public.

However, there are some disadvantages too. Management is more complicated because all operations are conducted in mixtures of different age classes. Harvesting operations are usually more difficult and expensive, and a larger area must be covered to get a given volume. Logging damage to and death of reserved trees is difficult to prevent.

Under ideal uneven-aged silviculture, the mature trees are removed as scattered individuals or small groups at relatively short intervals. The interval is based on growth rate, stand condition, and the size of the desired

Figure 3.—An unmanaged even-aged white spruce-balsam fir flat.



harvest; but in all cases, the eventual goal is a sustained yield of products. Trees should be marked before harvesting. In the initial applications of silvicultural treatments to previously unmanaged stands, the marked trees are usually the undesirable trees that do not meet the quality standards for veneer logs or sawlogs now or prospectively.

The percentage of these undesirable trees diminishes with succeeding harvests. Generally, this is the marking priority: (1) poor-risk trees or those assumed to be doomed before next harvest; (2) poor-quality trees; (3) slow-growing trees; (4) trees of less desirable species; (5) trees whose removal will improve spacing in the reserve stand; and (6) mature trees of good quality, good risk, desirable species, and fast growth. And to make optimum use of growing space, the marking should leave a reasonably even distribution of acceptable trees. These trees are classed as crop trees or potential crop trees and meet product requirements now or are expected to in the future.

Table 3 (appendix) is a suggested tree classification for red spruce and balsam fir that may be used to select trees to be harvested or to be retained. It takes into consideration crown class, vigor, and live-crown ratio and shows the average 10-year diameter growth for trees in each class. Vigor-class definitions are also given in the appendix.

Each periodic operation is a combined harvest, intermediate thinning, and timber-stand improvement because trees in all size classes are included. Therefore there are usually no separate non-commercial thinning operations as in even-aged management, although initial harvest may be unprofitable if a large percentage of defective trees are cut.

When properly employed, the selection method perpetuates a well-stocked stand of the more vigorous, fast-growing, and well-formed trees distributed among all size classes (fig. 4).

Operating Interval

On the better sites and on accessible areas, the operating interval should not exceed 10 to 15 years, especially if the stand runs heavy to balsam fir. On the poorer sites and on less ac-

cessible areas, economic considerations may cause the operating interval to be as long as 20 to 25 years, although losses to mortality and defect may be relatively high.

Stocking and Stand Structure

Little research information is available for determining the best stocking and stand-structure goals to work toward in any specific forest situation. Selection of these goals is largely a matter of judgment. Probably there is little difference in growth of stands ranging from less than 75 square feet of basal area to as much as 150 square feet of basal area per acre in trees over 0.5 inches d.b.h. Dense stands heavily thinned to about 50 percent of initial basal area often continue to grow at a rate approximating former growth. Residual trees in these stands usually respond to release and can double and even triple former performance.

Balanced uneven-aged stand structures are presented as tentative goals in table 4 (appendix).

Figure 4.—A well-stocked stand of well-formed trees being perpetuated by the selection method of silviculture.



Growth and Yield

Management practices have the strongest influence on net growth. Any practice that increases the percentage of softwood species will also increase net growth. Spruce and fir make major contributions to net growth in all stand types. Safford (1968) found that the average net annual growth that can be expected from stands receiving a minimal silvicultural input is about 50 cubic feet per acre in softwood stands (66 to 100 percent softwood species) and 40 cubic feet per acre in mixed-wood stands (21 to 65 percent softwood species). Table 5 (appendix) shows average net annual growth per acre by individual species.

Net growth during the first 10 years after partial stand removal in primary softwood stands ranged from 47 to 82 cubic feet per acre annually in several experimental areas in northern Maine. However, in primary softwood stands on rather poor sites on the Penobscot Experimental Forest in Maine, where unmanaged stands are being converted to managed stands, 10-year periodic results indicate a net annual growth of only 45 to 56 cubic feet per acre. Similar data for secondary softwood sites are not available.

Trends from experimental data have shown

that well-managed stands on reasonably productive sites can produce nearly twice as much merchantable wood as unmanaged stands over the course of a rotation, primarily because of the anticipation and salvage of natural mortality.

Even-aged Silviculture

Even-aged silviculture involves a series of intermediate operations followed by regeneration harvests at the end of each rotation. There may be a single final harvest as in clear-cutting or more than one harvest as in the shelterwood method or in the seed-tree method.

Natural Regeneration Methods

Clearcutting is a good method to apply in mature or overmature stands or where partial removal would result in considerable damage or mortality to the residual trees. Stands in which mechanical harvesters are to be used usually must be either clearcut or subjected to a strip clearing operation (fig. 5). If the strips are narrow—no wider than half the height of the trees being harvested—the method can be

Figure 5.—Large machines can operate in relatively narrow strips. Few residuals are left standing within the strip, and damage to edge trees need not occur.



considered a variant of the shelterwood method.

Clearcutting for regeneration requires that all trees down to 1 or 2 inches in diameter are felled. Because of the large volume of wood removed, this method entails the lowest cost for temporary logging improvements per unit of volume. When properly distributed, clearcutting increases the capacity of the forest property to support wildlife by increasing available browse.

However, clearcut land may be left with limited means for regeneration unless advance reproduction is present, a seed source is available, or immediate planting is carried out. A harsh micro-environment can develop, making regeneration difficult. Slash may smother advance reproduction or hinder the establishment of new seedlings. Slash can also increase the fire hazard. However, slash problems on mechanized operations having a high degree of utilization are minimized because the slash is more evenly distributed and piles containing large materials are not accumulated. Esthetically, a clearcut area may present an unattractive appearance to some people until it greens up with a ground cover of herbs, shrubs, and trees. This process usually takes 2 or 3 years but begins the same year as the harvest.

Some of these disadvantages can be minimized by clearcutting in either alternate or progressive strips or in patches. Openings wider than one tree height are suggested for areas where environmental conditions within the openings will not become too severe for successful regeneration. In these areas, the distance that the seeds are disseminated often regulates the width of the opening. For balsam fir and black spruce, openings should be no more than 2.5 to 3.0 chains wide; and for red spruce and white spruce, they should be no more than 6.0 chains wide.

On hot dry sites and on areas subjected to excessive wind damage, narrow strips or small patches of a width not exceeding half the height of the trees being harvested are necessary to obtain maximum shelter from the residual stand. This procedure should improve seedling survival by providing more moderate surface temperatures and higher soil moisture.

After the initial openings in the stand are

regenerated, adjacent areas can be cleared. The second operation will normally take place 3 to 10 years after the first operation. Uncut residual strips or patches should be at least 1 chain wide and preferably wider to help insure windfirmness in the residual trees.

Another desirable procedure for obtaining natural regeneration is the shelterwood system. In this method, at least two harvests are made. The first harvest, made to establish reproduction, should be made in a good seed year. About one-third to one-half of the basal area of the stand should be removed at this time, and the cut should be uniformly distributed. Harvests greater than this might leave the stand susceptible to wind damage. This harvest should remove the least desirable trees, leaving the larger and more vigorous trees of desirable species to provide seed. Factors to consider in tree selection are: susceptibility to wind damage; reduction of seed sources of less desirable species; and the spacing, vigor, and quality of the reserve stand. When the regeneration is well established, the remainder of the original stand can be harvested in one or more operations (fig. 6).

Figure 6.—Shelterwood system being employed in a spruce-fir stand. When the area has regenerated, the residual trees will be harvested.



Because the spruces and fir are shallow-rooted species, the seed-tree method of regeneration is not recommended because of potential wind damage.

Artificial Regeneration

In areas where natural regeneration is inadequate or unlikely to develop in a reasonable length of time, it may be necessary to resort to direct seeding or planting. Spruce is presently recommended over fir.

Artificial regeneration should be limited to areas where the environmental conditions are satisfactory for seed germination and seedling survival. Only the best seed or planting stock should be used. And when genetically improved stock is available, it should be used. This possibility in itself is a major advantage of clearcutting followed by planting.

When either seeding or planting are planned, the need for site preparation must be considered. Seeding on scarified seedbeds and planting on sites free of vegetative competition will allow new seedlings to survive and grow more rapidly. This is important because they will then be better able to compete with any natural regeneration that might develop.

Site Preparation

Generally the spruces and fir regenerate best on a mineral-soil seedbed because of more favorable temperature and moisture conditions. However, relatively little mineral soil is exposed during a harvesting operation, except in the skidroads. Logging operations conducted in the summer will, in some instances, expose more mineral soil than those done in the winter. Thus, in some situations, supplemental measures may be needed if seedbeds favorable for spruce-fir regeneration are to be provided.

Scarification should be only deep enough to mix the top 2 or 3 inches of mineral soil with the humus. A seedbed such as this not only will improve germination, but also will favor more rapid growth.

Some site-preparation work may also be needed before planting. Heavy accumulations of slash in clearcut areas may make the use of

mechanized planting equipment impossible and hand-planting slow and laborious. Cleaning the planting site of slash may be necessary. Several methods of treating slash are possible, ranging from crushing and chipping to removal from the site altogether.

In areas where seeding or planting of spruce or fir is planned, silvicides may be used to eliminate hardwood competition.

Intermediate Operations

A requirement of even-aged silviculture is the conduct of intermediate operations during the development of the stand. These include cleanings, thinnings, and intermediate harvests. Unlike stands being managed under the principles of uneven-aged silviculture, where each periodic operation can be a combination of timber-stand improvements as well as a harvest, even-aged silviculture often requires distinct and separate operations. And each intermediate operation is necessary if the full potential of the site is to be realized.

CLEANINGS

Cleaning is done in young stands not past the sapling stage. The objective is to free potential crop trees from other individuals of less desirable species or form that overtop or are likely to overtop the potential crop trees. This is also the time to rid the stand of unwanted holdovers from the previous stand.

Cleaning is the silvicultural tool that not only reduces the length of the rotation, but it is also the first attempt after the establishment of a new stand to alter species composition. Growth of merchantable trees is increased and wind-damage risk is reduced because of better development of crown and roots.

The need for cleaning in young spruce-fir stands depends on the intensity of competition. This in turn depends on site. On the primary softwood sites—poorly drained and shallow soils—spruce and fir are usually predominant and suffer little competition from hardwoods. Here, cleaning is usually not needed unless thickets have developed or if spruce is to be favored over fir and other softwoods.

On secondary softwood sites—deeper and

better drained soils—hardwoods are more aggressive. Much effort is required to bring the spruce and fir through this competition. A management decision must be made about whether to fight these hardwoods or to include them in the next timber crop. The landowner's objective, the relative value of the species involved, and the cost of cleaning operations are factors that enter into this decision. A single cleaning about 8 years after final harvest or when average height is 10 to 12 feet is usually enough to insure softwood dominance and improve individual tree growth, but occasionally follow-up treatments will be needed. Crop-tree spacing should be between 5 and 7 feet. Use the growing-stock guide for sapling stands to estimate the number of crop trees to release.

Current height growth of the spruce-fir is a good indicator of the need for cleaning. As long as terminal growth is greater than 6 inches annually, cleaning is not urgently needed (*Westveld 1953*).

Where spruce and fir are desired and hardwoods are not, spraying with an approved selective silvicide is suggested. This should be done after current spruce-fir growth has hardened off and winter buds have developed, but when the leaves on the hardwoods are still functioning.

Where both softwoods and hardwoods are desired, broadcast spraying of silvicides cannot be used. Treatment of individual stems, either by cutting or by application of approved chemicals, will be necessary to accomplish the cleaning job. Cleaning operations may take from 2 to 8 man-hours per acre, depending on the age of the stand, its composition, and its density.

Stand improvement with the use of mechanized equipment has been tried in other timber types with some success (*Dosen et al. 1958, Lotan 1967, Tackle and Shearer 1959*). The limited experience to date suggests that such an operation is best done in stands with trees between 10 and 20 feet tall. If the minimum width of strips cleared in this way is at least equal to the tree height, then a satisfactory growth response may follow in spruce-fir stands. However, because the techniques are not yet fully developed, specific recommendations cannot be made.

THINNINGS AND INTERMEDIATE HARVESTS

Thinning shortens the time it takes to bring trees to rotation size and also salvages a portion of trees that otherwise would be lost through mortality. Thinning begins with the selection of crop trees or potential crop trees to be carried through to maturity. These trees should be of the most desirable species and of the highest quality. They should be evenly distributed through the stand.

With even-aged management, stands will probably need an initial thinning at 25 to 35 years of age, followed by periodic thinnings or intermediate harvests at 10- to 20-year intervals. When planning these operations, use the B-level in the growing-stock guide (fig. 7)—depending on mean stand diameter—to determine the minimum reserved stocking.

Stands with a high proportion of fir should be thinned first. Those having a high proportion of spruce can be delayed unless competition is severe. The first thinning may be a pre-commercial one, but succeeding thinnings should yield commercial harvests (at least 5 cords per acre). Remove fir and retain spruce if the quality of fir is below that of the spruce or if spruce is being favored over fir. In stands containing hemlock, favor hemlock over fir if the quality of the fir is poor.

Timber removals for thinnings or for intermediate harvests on primary softwood sites should not exceed 10 to 40 percent of the total basal area. For secondary softwood sites, 30 to 50 percent may be removed at any one time. Removals in excess of these amounts may result in substantial wind damage. Amounts to remove vary with conditions of the site. These percentages should take precedent over removals specified by the B-level in the growing-stock guide.

Growth responses to thinning in white spruce trees approaching maturity are significant when trees are released on at least three sides to a distance equal to crown diameter of the tree being released (*Frank 1973*). Similar thinning regimes are recommended at this time for other spruce and for fir.

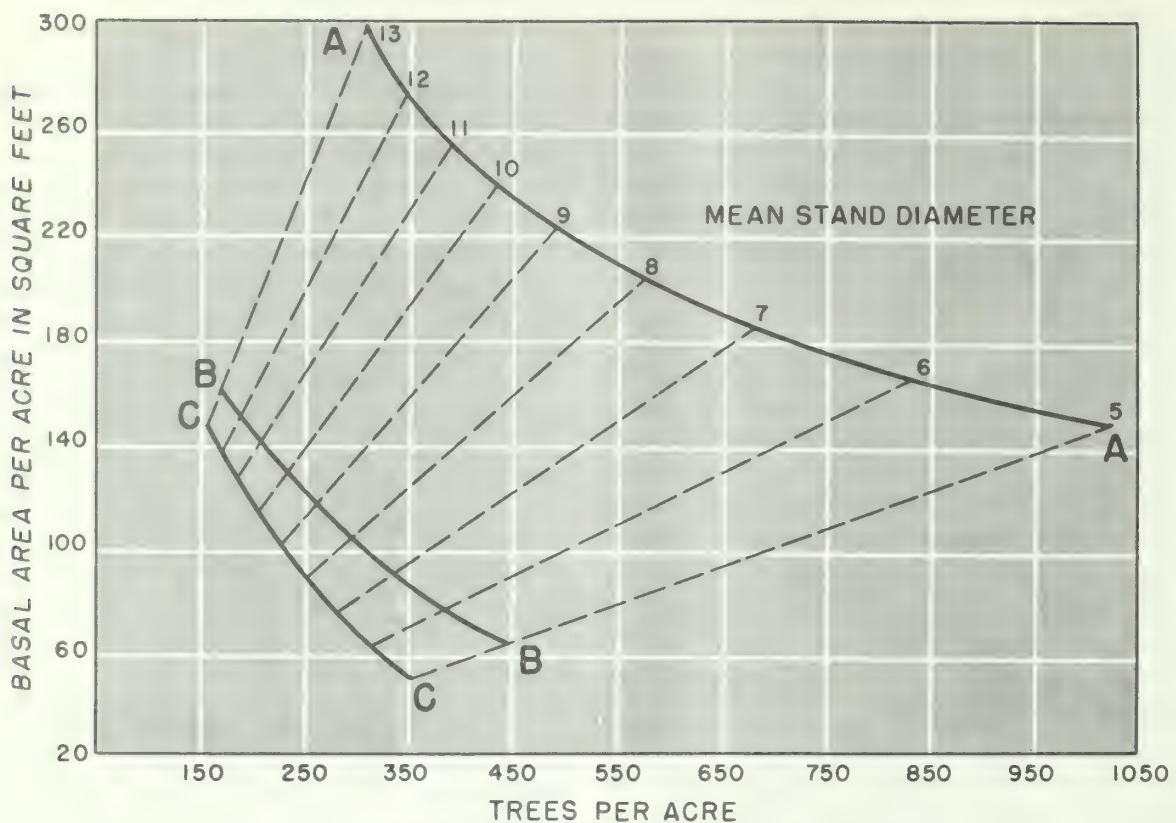


Figure 7.—Growing-stock guide for even-aged spruce-fir, based on the number of trees in the main canopy, average diameter, and basal area per acre. The area above the A-level represents overstocked stand conditions. Stands between the A- and B-levels are adequately stocked. Stands between the B- and C-levels should be adequately stocked within 10 years or less. Stands below the C-level are understocked.

Growing-Stock Guides

Growing-stock guides for even-aged spruce-fir stands with a mean stand diameter of at least 5 inches are given in figure 7. They apply to the trees in the main crown canopy and include the intermediate to dominant trees.

These guides are based on the number of trees per acre, the basal area per acre, and the mean diameter of the stand. The B-level represents minimum growing stock for adequate growth. The C-level represents the point where 10 years of growth will raise the stand to the B-level. The A-level represents an unmanaged stand on an average site. Stands above the A-level are overstocked; those between the A-level and B-level are adequately stocked; those between the B-level and C-level

are potentially adequately stocked; and those below the C-level are understocked.

For unmanaged even-aged sapling stands, average numbers of acceptable stems of growing stock required to produce at least a B-level stocking of crop trees are (Westveld 1941):

Mean stand diameter (inches)	Acceptable stems per acre (number)
1	1,660
2	1,345
3	1,075
4	850

Yields

Cubic foot yields per acre from fully-stocked, even-aged stands of second-growth

red spruce in the Northeast are given in table 1 (Meyer 1929). Because the yield relationship between sites and for stands within sites is not distinct, there is an overlapping of various sites and stand types for specific yield values. The yield values in table 1 are given for four combinations of sites and stand types. These yields are from so-called normal unmanaged stands. Yields from stands under a management scheme including periodic harvests or thinnings would be substantially higher over a rotation.

In general, stands fully stocked to spruce-fir on secondary softwood sites will yield greater volumes of wood than will similar stands on primary softwood sites.

SILVICULTURAL PRESCRIPTIONS

Stand Diagnosis

Before silvicultural prescriptions can be written for a stand, the management objective must be decided upon, and the stand must be described.

The limits of the stand to be considered and treated as separate entities must be delineated. The area included should be small enough to have reasonably similar stand and site conditions throughout, yet large enough to permit efficient harvesting.

Once the boundaries are known, then the stand diagnosis can be made.

Reproduction Stands

These stands are made up of stems at least 6 inches tall, but the mean stand diameter is less than 0.5 inches. Stems may be of seedling or sprout origin.

Percentage of stocking is needed for diagnosis. To determine the percentage of stocking in stands 10 acres and larger, locate randomly or systematically at least one milacre plot (3.72 feet in radius or 6.6 feet square) per acre. In stands smaller than 10 acres, locate a minimum of 10 milacre plots.

Tally each of these sample plots in one or more of the following stocking classes:

Stocking class 1.—Stocked with at least two spruce or fir trees.

Stocking class 2.—Stocked with at least one spruce or one fir and one other commercial species or stocked with at least two other commercial species.

Stocking class 3.—Not stocked.

In a reproduction stand, a stocked plot is one in which there is a minimum of two stems. For a plot to be tallied in stocking class 1, both stems must be spruce-fir, otherwise the tally will be in stocking class 2. A plot will be tallied as stocking class 3 if the above requirements are not met.

To determine the percentage of stocking, divide the number of plots in each stocking class by the total number of milacre plots and multiply by 100. A tally sheet for recording this information is given as figure 8 (appendix).

Table 1.—Cubic-foot yield per acre of fully stocked, even-aged stands of second-growth red spruce* in the Northeast by stand age, site, and stand type

Age (years)	Secondary softwood site (lower slopes, old farmland)	Primary softwood site (flats, old farmland); and secondary softwood site (lower slopes, old farmland)	Primary softwood site (swamps, flats, upper slopes, old farmland); and secondary softwood site (lower slopes)	Primary softwood site (swamps, upper slopes)
40	Cu. ft. 1,650	Cu. ft. 1,110	Cu. ft. 600	Cu. ft. 138
50	3,770	2,760	1,670	480
60	5,550	4,200	2,750	940
70	6,620	5,150	3,470	1,400
80	7,280	5,700	3,920	1,670
90	7,650	6,000	4,160	1,800
100	7,870	6,190	4,310	1,900

* Based on the merchantable cubic-foot volume in trees in the 4-inch and larger diameter classes from a 1-foot stump to a top of 3 inches inside bark.

Sapling Stands

A sapling stand is one in which the mean stand diameter is between 0.5 and 4.5 inches. To diagnose these stands, determine the mean d.b.h. of the trees in the main crown canopy for spruce, fir, and all other commercial tree species. This can be estimated or based on a few measurements. Number of milacre plots per acre is similar to those required for reproduction stands.

In sapling stands, a stocked plot is one in which at least one of the diameter classes listed below has the indicated number of potential crop trees of spruce-fir (stocking class 1) or other commercial species (stocking class 2).

Diameter class (inches)	Acceptable stems per plot (number)
0.5 to 1.4	2
1.5 to 2.4	1
2.5 to 3.4	1
3.5 to 4.4	1

A plot with only a single 1-inch spruce or fir but with a 1-inch tree of some other species will be tallied in stocking class 2. A plot not meeting any of these requirements will be classed as not stocked (stocking class 3).

To determine the percentage of stocking, divide the number of plots in each stocking class by the total number of milacre plots and multiply by 100. Use the tally sheet (fig. 8) for recording this information.

Poletimber and Sawtimber Stands

These are stands with average diameters of 4.5 inches and larger. To diagnose these stands, you need to know the number of trees per acre and the basal area per acre. For even-aged stands, you also need to know the mean diameter of the stand.

First, classify the stand as even-aged or uneven-aged and as whether it occurs on a primary or secondary softwood site. Indicate if even-aged or uneven-aged management is planned. Use the tally sheet (fig. 9, appendix) for recording these data.

Then in stands 10 acres and larger, locate randomly or systematically at least one sample point per acre. In stands smaller than 10 acres, locate a minimum of 10 sample points.

Use a prism or an angle gauge at each point to determine the trees of commercial species to be measured and recorded. A 10-factor instrument is recommended. Distances to borderline trees should be measured. A listing of distances for instruments having a factor of 10 is in table 6 (appendix).

When all sample points have been measured, compute the number of trees per acre.

To determine the number of trees per acre by diameter classes, divide the tree count in each diameter class by the total number of sampling points and then multiply by the conversion factor on the tally sheet.

EVEN-AGED MANAGEMENT

Determine whether the stand is mature or immature and record these data on the tally form (fig. 9, appendix). In a mature even-aged stand, more than 50 percent of the total basal area is in trees of the size being managed for, in fir trees that have reached pathological rotation, or in a combination of both. In an immature stand less than 50 percent of the basal area is in trees of this kind. Visual observation can be used for this determination. Otherwise, use data from sample points supplemented with increment borings from fir for determination of age.

For even-aged management, the tree count should include only those intermediate to dominant trees that make up the main crown canopy.

Basal area per acre is found by dividing the total tree count by the total number of sampling points and multiplying by the prism or gauge factor.

The mean d.b.h. of an even-aged stand can be estimated from the growing-stock guide (fig. 7), using the basal area per acre and the number of trees per acre.

In addition, in mature stands only, estimate the stocking of reproduction and sapling stems. To do this, use the sample point as the center of a milacre plot and record whether these plots are stocked with spruce-fir, stocked with other commercial species, or not stocked. Use the tally form (fig. 9, appendix) for recording these data.

If an estimate of volume is desired, apply an

appropriate local volume table to the number of trees per acre by species and diameter class as shown on the tally sheet.

Next, complete the stand-diagnosis form (fig. 10, appendix). Then refer to the key to find the suggested prescription.

UNEVEN-AGED MANAGEMENT

Tally all trees in the 1-inch and larger diameter classes. If uneven-aged stands are being converted to even-aged strands, an estimate of reproduction and sapling stems is also required. Use the tally form (fig. 9) for recording these data.

Next, transfer the number of trees per acre by diameter classes from the tally sheet (fig.

9) to the stand-diagnosis form (fig. 11, appendix). Determine basal area per acre by diameter class and enter in the stand-diagnosis form. Also enter the data from the proper columns in table 4 for the operating interval desired. Be sure to use the data for the appropriate management objective.

Finally, use the following key to find the suggested prescription. For prescriptions 7, 8, 9, and 10, the differences by d.b.h. class that are excess may be harvested or removed in a timber-stand-improvement operation. But the total amount removed should not exceed the total differences between the stand estimate of basal area and the goal. Nor should the amount removed result in a stand susceptible to excessive wind damage.

THE KEY

I. Reproduction and Sapling Stands

Mean Stand Diameter Less Than 4.5 Inches

Stand Condition

Prescription

A. Mean stand diameter less than 0.5 inches	
B. Primary softwood site	
C. 50 percent or more of milacre sample plots are stocked with spruce-fir reproduction	1
CC. Fewer than 50 percent of milacre sample plots are stocked with spruce-fir reproduction	2
BB. Secondary softwood site	
D. 50 percent or more of milacre sample plots are stocked with spruce-fir reproduction	3
DD. Fewer than 50 percent of milacre sample plots are stocked with spruce-fir reproduction but total stocking is 50 percent or more	4
DDD. Total stocking of reproduction is less than 50 percent	2
AA. Mean stand diameter between 0.5 and 4.5 inches	
E. Primary softwood site	
F. 50 percent or more of milacre sample plots are stocked with spruce-fir saplings	5
FF. Fewer than 50 percent of milacre sample plots are stocked with spruce-fir saplings	2
EE. Secondary softwood site	

<i>Stand Condition</i>	<i>Prescription</i>
G. 50 percent or more of milacre sample plots are stocked with spruce-fir saplings	6
GG. Fewer than 50 percent of milacre sample plots are stocked with spruce-fir saplings but total stocking is 50 percent or more	4
GGG. Total stocking of saplings is less than 50 percent	2

II. Poletimber and Sawtimber Stands

Mean Stand Diameter 4.5 Inches and Larger

- A. Uneven-aged stand
 - B. For maintaining uneven-aged stand condition
 - C. Primary softwood site
 - D. Commercial harvest feasible of at least 5 cords per acre
 - DD. Commercial harvest not feasible
 - CC. Secondary softwood site
 - E. Commercial harvest feasible of at least 5 cords per acre
 - F. Spruce-fir represents at least 50 percent of total basal area
 - FF. Hardwoods represent more than 50 percent of total basal area
 - FFF. Spruce-fir and hardwoods each representing less than 50 percent of total basal area and other softwoods (principally hemlock) accounting for remainder
 - EE. Commercial harvest not feasible
 - G. Spruce-fir represents at least 50 percent of total basal area
 - GG. Hardwoods represent more than 50 percent of total basal area
 - GGG. Spruce-fir and hardwoods each representing less than 50 percent of total basal area and other softwoods (principally hemlock) accounting for the remainder
 - BB. For converting to even-aged stand condition
 - H. Primary softwood site

Stand Condition

Prescription

I.	50 percent or more of milacre sample plots are stocked with spruce-fir reproduction	11
II.	Fewer than 50 percent of milacre sample plots are stocked with spruce-fir reproduction	12
HH.	Secondary softwood site	
J.	50 percent or more of milacre sample plots are stocked with spruce-fir reproduction	11
JJ.	Fewer than 50 percent of milacre sample plots are stocked with spruce-fir reproduction but total stocking is 50 percent or more	13
JJJ.	Total stocking of reproduction is less than 50 percent	12
AA.	Even-aged stand	
K.	For maintaining even-aged stand condition	
L.	Primary softwood site	
M.	Mature stand	
N.	50 percent or more of milacre sample plots are stocked with spruce-fir reproduction	11
NN.	Fewer than 50 percent of milacre sample plots are stocked with spruce-fir reproduction	
O.	Growing stock above the B-level	12
OO.	Growing stock below the B-level	14
MM.	Immature stand	
P.	Growing stock above the B-level	15
PP.	Growing stock below the B-level	16
LL.	Secondary softwood site	
Q.	Mature stand	
R.	50 percent or more of milacre sample plots are stocked with spruce-fir reproduction	11
RR.	Fewer than 50 percent of milacre sample plots are stocked with spruce-fir reproduction but total stocking may be 50 percent or more	
S.	Growing stock above the B-level	13
SS.	Growing stock below the B-level	17

*Stand Condition**Prescription*

QQ. Immature stand	
T. Spruce-fir represents at least 50 percent of total basal area	
U. Growing stock above the B-level	15
UU. Growing stock below the B-level	16
TT. Hardwoods represent more than 50 percent of total basal area	
V. Growing stock above the B-level	18
VV. Growing stock below the B-level	19
KK. For converting to uneven-aged stand condition	
W. All stands	20

The Prescriptions

1. This stand should develop naturally into a spruce-fir stand. Consider eliminating competing vegetation, including hardwoods. Otherwise do nothing now. Examine in 5 years.
2. This stand may not develop within 5 years into a stand satisfactorily stocked with spruce-fir reproduction or saplings. Consider preparing the site and direct-seed or plant spruce and fir on those areas not stocked with spruce-fir, but only if the non-stocked areas have potential for spruce-fir. Otherwise do nothing now. In either case, examine in about 5 years.
3. Begin a cleaning operation to eliminate the competing vegetation, including hardwoods, if the management decision is to favor spruce-fir. If the spruce-fir is in competition with other softwoods, do nothing now. If the decision is to manage for all species, begin a cleaning operation to favor potential crop trees of any species. In all cases, examine in 5 years.
4. This stand may not develop within 5 years into a stand satisfactorily stocked with spruce-fir reproduction or saplings. If the management decision is to regenerate spruce-fir, prepare the site and direct-seed or plant spruce or fir on areas not stocked with spruce-fir reproduction, but only if the non-stocked areas have potential for spruce-fir. If the decision is to manage for all species, begin a cleaning operation to favor potential crop trees of any species. In either case, examine in 5 years.
5. This stand should naturally develop into a spruce-fir stand. If competition from other species appears to be slowing stand development or if a spruce-fir thicket is developing or has developed, begin a cleaning operation. Use growing-stock guide for number of acceptable stems per acre. Examine in 5 years.
6. Begin a cleaning operation to eliminate the competing species if the management decision is to favor spruce-fir. If the decision is to manage for all species, begin a cleaning operation to favor potential crop trees of any species. Use growing-stock guide for number of acceptable stems per acre. In either case, examine in 5 years.
7. Use the stand-diagnosis form (see fig. 11, appendix) to determine if any of the diameter classes are overstocked. Mark heavier in these classes, keeping spacing in mind, and using the marking guides and table 3, appendix. If practical, the

commercial harvest should be conducted in a good spruce or fir seed year. The seed crop can take advantage of the opening of the stand and of any seedbed scarification that has occurred. Depending on site, the harvest should not remove more than 10 to 50 percent of the total basal area per acre; and at least 80 to 120 square feet of basal area per acre should be retained. If this minimum amount of residual growing stock is not possible because of poor quality, consider converting to even-aged silviculture. Examine again at the end of the operating interval.

8. Consider timber-stand improvement to favor crop trees of desired species. Examine in about 10 years.
9. If the management decision is to favor spruce-fir and the spruce-fir growing-stock component is adequate for management, use the stand-diagnosis form (fig. 11, appendix) to determine what diameter classes are overstocked. Mark heavier in these classes and keep spacing in mind, using the marking guides and table 3, appendix. Examine in about 10 years. If the spruce-fir growing stock component is not considered adequate, convert to even-aged silviculture. If the decision is to manage for all species, see the Silvicultural Guide for Northern Hardwoods in the Northeast or for Paper Birch in the Northeast.
10. If the management decision is to favor spruce-fir, begin a timber-stand-improvement operation to favor crop trees of desired species and to remove undesirable trees. Examine in about 10 years. If the spruce-fir component is not considered adequate, convert to even-aged silviculture. If the decision is to manage for all species, see the Silvicultural Guide for Northern Hardwoods in the Northeast or for Paper Birch in the Northeast.
11. Harvest all merchantable trees and fell all other trees 1 to 2 inches and larger in diameter. The size and shape of the clearings selected should provide environmental conditions suitable for natural regeneration. Examine in about 5 years.

12. To obtain spruce-fir regeneration, apply the first harvest of a shelterwood cutting or clearcut narrow strips. If artificial regeneration is necessary, clearcut and prepare the site; and direct-seed or plant spruce or fir on those areas not stocked with spruce-fir. In either case, examine in about 5 years.
13. If the management decision is to regenerate spruce-fir, remove a portion of the trees by applying the first harvest of a shelterwood cutting or clearcut narrow strips. Consider preparing the site, and direct-seed or plant spruce or fir on areas not stocked with spruce-fir reproduction. Hardwood sprouts may have to be controlled. Examine in about 5 years. If the decision is to manage for all species, harvest all merchantable trees and fell all other trees 1 to 2 inches and larger in diameter. The size and shape of the clearings selected should provide environmental conditions suitable for natural regeneration. Examine in about 5 years. If hardwoods account for 50 percent or more of the stocking in reproduction, see the Silvicultural Guide for Northern Hardwoods in the Northeast or for Paper Birch in the Northeast.
14. To obtain spruce-fir regeneration in a reasonable period of time, artificial methods are probably necessary. Clearcut, then prepare the site and direct-seed or plant spruce or fir on areas not stocked with spruce-fir. Examine in about 5 years.
15. Begin a periodic harvest program if a commercial harvest is feasible. Otherwise consider a timber-stand-improvement operation. Examine in about 10 years or at the next operating interval.
16. Consider a timber-stand-improvement operation. Otherwise do nothing now. Examine in about 10 years. If growing stock is below the C-level, consider preparing the site; and direct-seed or plant spruce or fir on areas not stocked with spruce-fir. Examine in about 5 years.
17. If the management decision is to regenerate spruce-fir, harvest all merchantable trees and fell all other trees 1 to 2 inches and larger in diameter. Then prepare the

- site and direct-seed or plant spruce or fir on areas not stocked with spruce-fir reproduction. Examine in about 5 years. If the decision is to manage for all species, harvest all merchantable trees and fell all other trees 1 to 2 inches and larger in diameter. Examine in about 5 years. If hardwoods account for 50 percent or more of the stocking in reproduction, see the Silvicultural Guide for Northern Hardwoods in the Northeast or for Paper Birch in the Northeast.
18. If the management decision is to favor spruce-fir, begin a periodic harvest program if a commercial harvest is feasible. Otherwise consider a timber-stand-improvement operation. In either case, examine in about 10 years. If the decision is to manage for all species, see the Silvicultural Guide for Northern Hardwoods in the Northeast or for Paper Birch in the Northeast.
 19. Conduct a timber-stand-improvement operation if the management decision is to favor spruce-fir. Examine in about 10 years. If growing stock is below the C-level, consider preparing the site and direct-seed or plant spruce or fir on areas not stocked with spruce-fir. Examine in about 5 years. If the decision is to manage for all species, see the Silvicultural Guide for Northern Hardwoods in the Northeast or for Paper Birch in the Northeast.
 20. Make a series of partial harvests or conduct timber-stand-improvement operations at intervals not exceeding 5 to 10 years. These cuttings should remove small groups of several trees scattered through the stand to stimulate regeneration. The trees to be removed should be marked. The objective is to develop a diameter distribution that will plot as an inverted J-shaped curve. Consider preparing the site and direct-seed or plant spruce or fir on areas not stocked with spruce-fir. If hardwoods represent more than 50 percent of the basal area and the decision is to manage for all species, see the Silvicultural Guide for Northern Hardwoods in the Northeast or for Paper Birch in the Northeast.

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APPENDIX

Vigor Class Definitions*

Vigor I

Crown well developed, usually symmetrical; no dead branches in live crown. *Branches* long and slender, up-turned at least 15 degrees from horizontal except near bottom of crown; recent terminal and lateral growth good (at least 8 inches and averaging 10-12 inches except in heavy seed year). *Needles* long and lustrous, bluish-green for fir and slightly yellowish-green for spruce, growing densely on twigs; and on fir up-turned instead of flat on twigs. *Bark* on fir light gray, tight, smooth, and shiny, with many pitch blisters; on spruce, reddish and shredded on young trees, in large, thin, loose plates on mature trees.

Vigor II

Crown of poorer form than in Vigor I but giving the general impression of being healthy without making rapid growth; if large, crown may be fairly open, but if small, should be fairly dense; dead branches in crown limited to a few small ones. *Branches* may be shorter and less slender than in Vigor I but not stubby and heavy; horizontal or slightly drooping except may be slightly up-turned near top; terminal and lateral twig growth last few years usually fair to good (3 to 8 inches, except somewhat less during heavy seed years) although slow growth is admissible if crown form is otherwise good. *Needles* flattened on fir twigs and a deeper green with less bluish cast and not so dense on twigs as in Vigor I; spruce needles shorter, less

lustrous and not so closely spaced on twigs. *Bark* on fir usually smooth, dirty gray, not shiny, pitch blisters less conspicuous; on spruce, rougher and more brownish on young trees, darker brown and with plates smaller and tighter than on Vigor I trees.

Vigor III

Crown of poor form (open, one-sided or thin), but not dying; may have dead branches in live crown. Branches may be short and stout, or if slender, foliage very sparse, horizontal or more commonly drooping, especially at tips; terminal and lateral growth very poor (less than 3 inches), except may occasionally be fair on trees with otherwise poorly developed crowns. *Needles* flat on fir twigs, widely spaced, often dull, unhealthy color; on spruce, short, not lustrous, and frequently yellowish, very slender and brittle, and appearing sparse or scattered on twigs. *Bark* on fir dark gray or almost brown, thick, rough and often broken into small scales on old trees, dirty dull gray on young trees, never smooth and shiny, pitch blisters inconspicuous or lacking; on spruce, dark brown to almost black, with scales smaller and heavier on young trees, thick, ridged, and fissured, and often reddish brown on old trees.

* McLintock, T. F. 1958. A tree classification for red spruce and balsam fir. U. S. Forest Service NE. Forest Exp. Sta. office report, 33 p.

Table 2.—Some silvical characteristics of balsam fir and the spruces

Species	Relative shade tolerance	Relative growth rate	Good cone crop frequency	Effective seed dispersal
Balsam fir	Very tolerant	Fast	Years 2-4	Feet 100
Black spruce	Tolerant	Slow-medium	4	100
White spruce	Tolerant	Fast	2-6	300
Red spruce	Tolerant to very tolerant	Medium	3-8	200

Table 3.—Tree classification for red spruce and balsam fir*

Tree class	Rating as growing stock	Vigor	Crown class	Crown ratio	Average 10-year diameter growth
<i>RED SPRUCE</i>					
<i>Inches</i>					
A	Superior	I	Dominant & intermediate	0.6+	1.8
B	Good	I	Dominant & intermediate	.3-.5	1.3
C	Acceptable	II	Overtopped	0.6+	
			Intermediate	0.6+	.9
D	Inferior	II	Dominant	0.3+	
E	Undesirable	III	Intermediate	0.3+	.6
			All other trees with a crown ratio of under .3		.2
<i>BALSAM FIR</i>					
A	Superior	I	All classes	0.7+	2.4
B	Good	I	All classes	.5-.6	1.8
		II	All classes	0.7+	
C	Acceptable	I	All classes	.3-.4	
		II	All classes	.3-.6	1.2
D	Inferior	III	Dominant & intermediate	0.5+	.8
E	Undesirable	III	Overtopped	0.5+	.4
			All other trees with a crown ratio of under .3		

* McLintock, T. F. 1958. A tree classification for red spruce and balsam fir. USDA Forest Serv. NE. Forest Exp. Sta. office report. 33 p.

Table 4.—Stocking goals for uneven-aged stands at the start of 5-, 10-, and 20-year operating intervals, by management objective, number of trees per acre, and basal area per acre

D.b.h. class (inches)	Management objective 1: Pulpwood product; Operating interval						Management objectives 2, 3, and 4: Multiple product; Operating interval												
	5-year			10-year			20-year			5-year			10-year			20-year			
	Trees	Basal area	Sq. ft.	Trees	Basal area	Sq. ft.	Trees	Basal area	Sq. ft.	Trees	Basal area	Sq. ft.	Trees	Basal area	Sq. ft.	Trees	Basal area	Sq. ft.	
1	No.	Sq. ft.	No.	Sq. ft.	No.	Sq. ft.	No.	Sq. ft.	No.	No.	Sq. ft.	No.	No.	Sq. ft.	No.	No.	Sq. ft.		
1	514	3	459	2	370	2	173	1	153	1	122	1	122	1	122	1	122	1	
2	343	8	306	7	246	5	135	3	118	3	96	3	96	3	96	2	96	2	
3	229	11	204	10	164	8	104	5	92	5	74	4	74	4	74	4	74	4	
4	152	13	136	12	110	10	80	7	70	6	57	5	57	5	57	5	57	5	
5	102	14	91	12	73	10	61	8	54	7	44	6	44	6	44	6	44	6	
6	68	13	60	12	49	10	47	9	41	8	33	7	33	7	33	7	33	7	
7	45	12	40	11	32	9	36	10	32	9	26	7	26	7	26	7	26	7	
8	30	10	27	9	22	8	28	10	25	9	20	7	20	7	20	7	20	7	
9	20	9	18	8	14	6	21	9	19	8	16	7	16	7	16	7	16	7	
10	13	7	12	7	10	5	16	9	14	7	12	6	12	6	12	6	12	6	
11	9	6	8	5	6	4	13	8	11	7	9	6	9	6	9	6	9	6	
12	6	5	5	4	4	3	10	8	7	7	5	5	5	5	5	5	5	5	
13	4	4	4	3	3	2	—	—	—	6	4	4	4	4	4	4	4	4	
14	3	3	3	2	2	—	—	—	—	5	3	3	3	3	3	3	3	3	
15	2	2	—	—	—	—	—	—	—	3	2	2	2	2	2	2	2	2	
16	—	—	—	—	—	—	—	—	—	2	1	1	1	1	1	1	1	1	
17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
19	Total	1,540	120	1,372	105	1,100	80	750	120	660	105	530	80	530	80	530	80	530	80

Table 5.—Average annual net growth per acre by species

Species	Softwood stands		Mixedwood stands	
	Cu. ft.	Pct.	Cu. ft.	Pct.
Pine	1.5	3	0.2	1
Spruce	25.0	51	15.8	39
Balsam fir	17.1	35	31.1	32
Hemlock	2.3	5	4.3	10
Cedar	2.0	4	2.0	5
Tamarack	.1	(^a)	(^b)	(^a)
All softwoods	48.0	98	35.5	87
Sugar maple	(^b)	(^a)	0.8	2
Red maple	1.5	3	3.7	9
Yellow birch	-.8	-2	-.1	(^a)
Paper birch	.4	1	1.0	2
Beech	.1	(^a)	.1	(^a)
Aspen	.1	(^a)	.2	(^a)
Other hardwoods	(^b)	(^a)	-.1	(^a)
All hardwoods	1.3	2	5.6	13
All species	49.3	100	41.1	100

^a Less than 0.5 percent.^b Less than 0.05 cubic feet.

Table 6.—Horizontal distances to borderline trees when using a 10-factor prism or angle gauge for trees 0.5 inches d.b.h. to 19.4 inches d.b.h.

D.b.h. (inches)	Distance (feet)	D.b.h. (inches)	Distance (feet)	D.b.h. (inches)	Distance (feet)	D.b.h. (inches)	Distance (feet)	D.b.h. (inches)	Distance (feet)
0.5	1.37	4.3	11.82	8.1	22.27	11.9	32.72	15.7	43.17
0.6	1.65	4.4	12.10	8.2	22.55	12.0	33.00	15.8	43.45
0.7	1.92	4.5	12.37	8.3	22.82	12.1	33.27	15.9	43.72
0.8	2.20	4.6	12.65	8.4	23.10	12.2	33.55	16.0	44.00
0.9	2.47	4.7	12.92	8.5	23.37	12.3	33.82	16.1	44.27
1.0	2.75	4.8	13.20	8.6	23.65	12.4	34.10	16.2	44.55
1.1	3.02	4.9	13.47	8.7	23.92	12.5	34.37	16.3	44.82
1.2	3.30	5.0	13.75	8.8	24.20	12.6	34.65	16.4	45.10
1.3	3.57	5.1	14.02	8.9	24.47	12.7	34.92	16.5	45.37
1.4	3.85	5.2	14.30	9.0	24.75	12.8	35.20	16.6	45.65
1.5	4.12	5.3	14.57	9.1	25.02	12.9	35.47	16.7	45.92
1.6	4.40	5.4	14.85	9.2	25.30	13.0	35.75	16.8	46.20
1.7	4.67	5.5	15.12	9.3	25.57	13.1	36.02	16.9	46.47
1.8	4.95	5.6	15.40	9.4	25.85	13.2	36.30	17.0	46.75
1.9	5.22	5.7	15.67	9.5	26.12	13.3	36.57	17.1	47.02
2.0	5.50	5.8	15.95	9.6	26.40	13.4	36.85	17.2	47.30
2.1	5.77	5.9	16.22	9.7	26.67	13.5	37.12	17.3	47.57
2.2	6.05	6.0	16.50	9.8	26.95	13.6	37.40	17.4	47.85
2.3	6.32	6.1	16.77	9.9	27.22	13.7	37.67	17.5	48.12
2.4	6.60	6.2	17.05	10.0	27.50	13.8	37.95	17.6	48.40
2.5	6.87	6.3	17.32	10.1	27.77	13.9	38.22	17.7	48.67
2.6	7.15	6.4	17.60	10.2	28.05	14.0	38.50	17.8	48.95
2.7	7.42	6.5	17.87	10.3	28.32	14.1	38.77	17.9	49.22
2.8	7.70	6.6	18.15	10.4	28.60	14.2	39.05	18.0	49.50
2.9	7.97	6.7	18.42	10.5	28.87	14.3	39.32	18.1	49.77
3.0	8.25	6.8	18.70	10.6	29.15	14.4	39.60	18.2	50.05
3.1	8.52	6.9	18.97	10.7	29.42	14.5	39.87	18.3	50.32
3.2	8.80	7.0	19.25	10.8	29.70	14.6	40.15	18.4	50.60
3.3	9.07	7.1	19.52	10.9	29.97	14.7	40.42	18.5	50.87
3.4	9.35	7.2	19.80	11.0	30.25	14.8	40.70	18.6	51.15
3.5	9.62	7.3	20.07	11.1	30.52	14.9	40.97	18.7	51.42
3.6	9.90	7.4	20.35	11.2	30.80	15.0	41.25	18.8	51.70
3.7	10.17	7.5	20.62	11.3	31.07	15.1	41.52	18.9	51.97
3.8	10.45	7.6	20.90	11.4	31.35	15.2	41.80	19.0	52.25
3.9	10.72	7.7	21.17	11.5	31.62	15.3	42.07	19.1	52.52
4.0	11.00	7.8	21.45	11.6	31.90	15.4	42.34	19.2	52.80
4.1	11.27	7.9	21.72	11.7	32.17	15.5	42.62	19.3	53.07
4.2	11.55	8.0	22.00	11.8	32.45	15.6	42.90	19.4	53.35

Note: Borderline distances for trees larger than 19.4 inches d.b.h. can be calculated by multiplying d.b.h. by 2.75.

TALLY SHEET AND STAND-DIAGNOSIS FORM
FOR REPRODUCTION AND SAPLING STANDS

Stand size class:

Reproduction

Sapling

Softwood site:

Primary

Secondary

Mean stand diameter in inches _____

Stocking Class	Plot count	Percent
1. Stocked with spruce-fir		
2. Stocked with other commercial species		
Total stocking		
3. Not stocked		
TOTAL, ALL CLASSES		100

Prescription: _____

Figure 8.—A tally sheet and diagnosing form for reproduction and sapling stands.

TALLY SHEET FOR
POLETIMBER AND SAWTIMBER STANDS

Stand Condition:

Even-aged

Mature

Immature

Uneven-aged

Type of Management:

Even-aged management

Uneven-aged management

Softwood site:

Primary

Secondary

D.b.h. class	Fir	Spruce	Other softwood	Paper birch	Other hardwood	Tree count	Conversion factor	Number Trees per acre
1							1,833	
2							458	
3							204	
4							115	
5							73	
6							51	
7							37.4	
8							28.6	
9							22.6	
10							18.3	
11							15.2	
12							12.7	
13							10.8	
14							9.4	
15							8.2	
16							7.2	
17							6.3	
18							5.7	
19							5.1	
20							4.6	
21							4.2	
22							3.8	
23							3.5	
TOTAL								

No. of sample points:	Milacres stocked:*	No.	%
	Spruce-fir	—	—
	Other species	—	—
	Total stocked	—	—
	Milacres not stocked	—	—
	Total milacres	—	—

*Milacres stocked should be tallied when: (a) uneven-aged stands are to be placed under even-aged management; (b) even-aged management is to be maintained in mature even-aged stands.

Figure 9.—A tally sheet for poletimber and sawtimber stands.

STAND-DIAGNOSIS FORM FOR EVEN-AGED MANAGEMENT

Management objective: _____

Number of trees per acre: _____

Basal area per acre: _____ sq. ft.

Mean diameter of stand: _____ inches

Milacres stocked:

Stocked with spruce-fir: _____ %

Stocked with other commercial species: _____ %

Total stocking: _____ %

Required basal area per acre at B-level: _____ sq. ft.

Basal area per acre above B-level: _____ sq. ft.

Available for harvest: _____ sq. ft. (some or all above

B-level depending on the windfirmness of the stand.)

Prescription: _____

Figure 10.—A stand-diagnosis form for even-aged management.

STAND-DIAGNOSIS FORM FOR UNEVEN-AGED MANAGEMENT

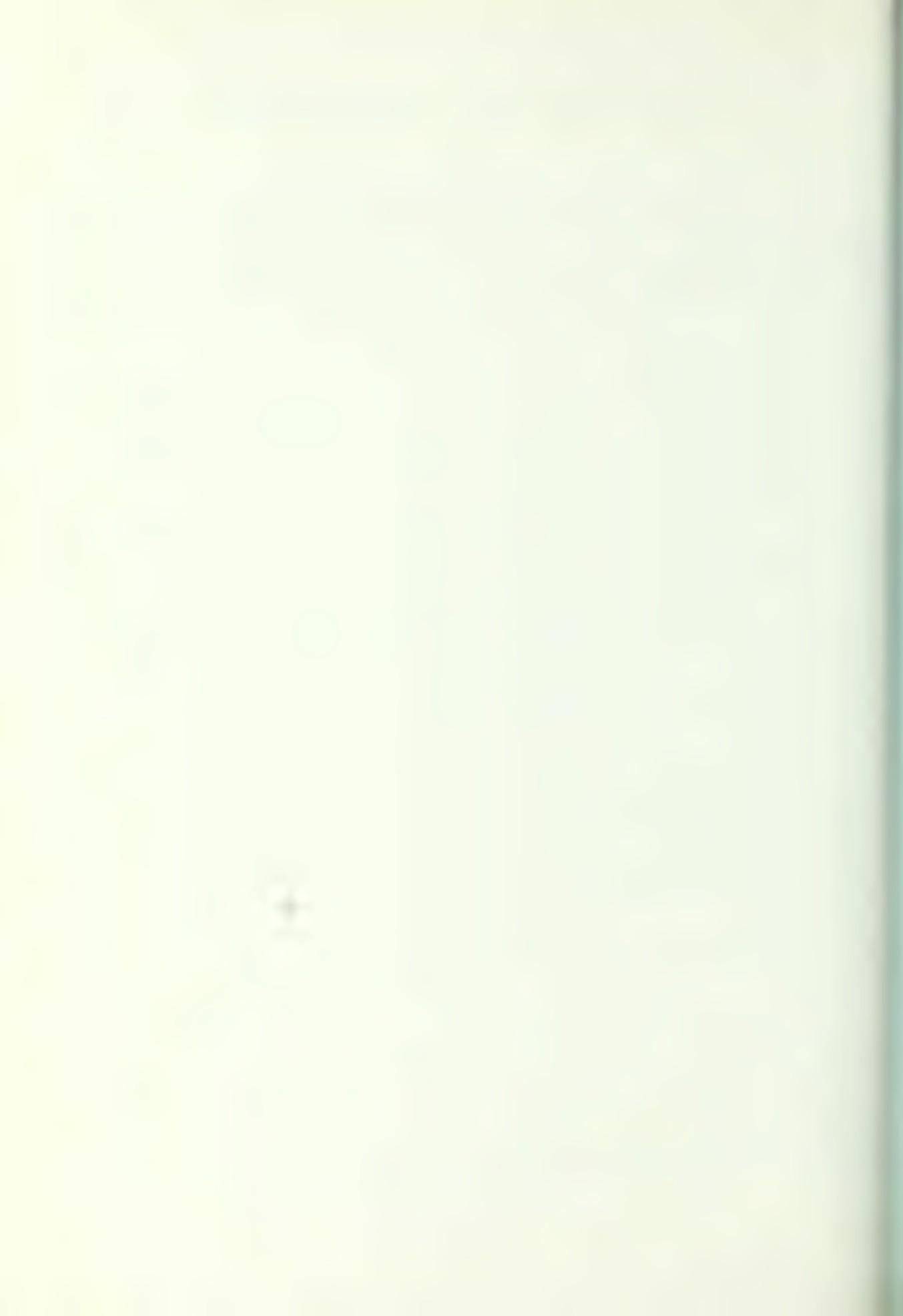
Management objective: _____

D.b.h. class (inches)	Number of trees per acre			Sq. ft. of basal area per acre		
	Tally sheet	Table 4 goal	Difference + -	Tally sheet	Table 4 goal	Difference + -
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20		X X X X			X X X X	
21		X X X X			X X X X	
22		X X X X			X X X X	
23		X X X X			X X X X	
TOTAL						

Computed amount of growing stock to be removed: _____ sq. ft. per acre

Prescription: _____

Figure 11.—A stand-diagnosis form for uneven-aged management.





THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.



A HISTORY of the NORTHEASTERN FOREST EXPERIMENT STATION 1923 to 1973



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NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

A HISTORY OF THE
NORTHEASTERN FOREST EXPERIMENT STATION

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A HISTORY of the NORTHEASTERN FOREST EXPERIMENT STATION 1923 to 1973

**by Susan R. Schrepfer
Edwin vH. Larson
Elwood R. Maunder**

Susan R. Schrepfer is research assistant in the Forest History Society, Santa Cruz, California, and Elwood R. Maunder is executive director of the Society. Edwin vH. Larson is editor and chief of publications at the Northeastern Forest Experiment Station.

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FIFTY YEARS !

FIIFTY YEARS AGO, the Northeastern Forest Experiment Station was established, the first federal forest research establishment in the Northeast. This history was prepared to celebrate that event.

The Northeastern Station began in 1923, at Amherst, Massachusetts, with a handful of scientists. A few years later, in 1927, another small research unit was established at Philadelphia, Pennsylvania—the Allegheny Forest Experiment Station. During World War II, when the Nation's efforts were turned all out for winning the war, forest research was reduced sharply. The Northeastern Station was closed, and its people and projects were transferred to the Allegheny Station.

As the war ended, the research effort was resumed. The Station—renamed the Northeastern Forest Experiment Station—began a steady expansion of its activities, which are now carried on at laboratories and field units in 14 states, by a staff of about 375 people.

BACKGROUND

The Beginnings of Forest Service Research

Nowhere is the scientific foundation of American forestry more dramatically told than in the history of the forest experiment stations established and maintained by the Forest Service of the U.S. Department of Agriculture.

Here is the story of nationally coordinated grass-roots efforts to solve the problems of forest conservation in each of the major forest regions of the United States—efforts that gradually came to encompass research on all the multiple uses of forest land: timber, water, recreation, wildlife, grazing, and environmental amenities.

This history of the Northeastern Forest Experiment Station would not be complete without a brief account of research in the Forest Service before 1923 and the conditions that led to creation of the experiment stations in the Northeast.

The period 1900 to 1915 was the infancy of Forest Service research. In 1909 and 1910 permanent sample plots were first established on the national forests and private lands for determining growth and yield of trees; cooperative studies of forest insects and tree diseases were begun by the Forest Service and the Bureaus of Entomology and Plant Industry; and the Forest Products Laboratory was established at Madison, Wisconsin, to specialize in wood-utilization research.

These early activities needed all the focus and muscle that administrative coordination within the Forest Service could give them. In 1912, district and central committees were organized to supervise all Forest Service research.

In 1915, all research—including that of the experiment stations, the Forest Products Laboratory, and the Branches of Products and Silviculture—was placed under a new Branch of Research, headed by Earle H. Clapp. Thus closer coordination was achieved through the direction of a single administrative unit within the Forest Service. The Branch of Research has governed the experiment stations from its inception till the present.

The First Experiment Stations

By 1921, eight forest experiment stations, designed to tackle regional forestry problems, had been established by the Forest Service. Though small and scantily funded, these stations marked a beginning.

The first experiment stations were all in the West, for good reasons. First, the early research was associated mainly with the national forests, and most of the national forests were in the West.¹ Second, at that time the extent and number of non-federal research programs already under way in the East lessened the urgency for federal research there.

The Yale School of Forestry had begun research projects; so had the New York State College of Forestry at Syracuse University. The Pennsylvania Department of Forests and Waters was conducting more than 60 research projects, and the Pennsylvania State College Department of Forestry operated a research program in association with the State Agricultural Experiment Station. The Maryland State Department of Forestry launched 30 forestry-research projects before 1927, and the New Jersey Department of Conservation and Development was engaged in 35. Connecticut and Vermont Agricultural Experiment Stations employed foresters, and two research foresters were on the staff of the New Hampshire Agricultural College. The Philadelphia and Reading Coal and Iron Company and the Wheeler and Dusenberry Lumber Company funded research programs.

Such developments made it possible for the Forest Service to concentrate its early research west of the Mississippi River.²

Research Needs in the Northeast

Despite state and private research efforts, the East had significant unsolved forestry problems. In 1919, Henry S. Graves, Chief of the Forest Service, reported that, although forestry on national forests had made great strides, private forest lands were rapidly being depleted. This was most obvious in the East, he continued, where the supplies of "all our

great centers of production" were "approaching exhaustion."

In 1922, William B. Greeley, Chief of the Forest Service, decried the fact that the large sawmills of the country were "in full migration westward to the last great virgin timber supply on the Pacific Coast."

Intensive harvesting had brought about serious depletion. For more than 200 years, the forests of southern New England and New Jersey had been drained again and again for lumber, shingles, ship timbers, and fuel wood. By the 1920s the heavily populated areas of the Northeastern and Middle Atlantic States were able to supply only a fraction of their lumber needs. The people of the East had to obtain their lumber from farther and farther west, paying progressively higher prices due to transportation costs. Many logging communities had become ghost towns.

After the Civil War, when the railroads began extensive shipment of western farm commodities to the East, many of the marginally profitable farms of the Northeast were abandoned and allowed to revert to forest.

Much of the second growth was of commercially less desirable species and of poor quality. By 1920 second and third growth was supplying much of the timber harvested in the Northeast.

Most of these forest lands in the Northeast were in small private ownerships; and owners of small forest tracts, particularly small farmers, could not afford—as big corporations could—to do their own research. Through the Department of Agriculture, the federal govern-

ment took up the responsibility for research to help forest-land owners, as it had for farmers.

In addition to the need for public action on timber culture on private land, it became obvious to the Forest Service that federal aid was also needed for research in insect and disease control, wood utilization, fire protection, watershed management, and wildlife habitat.

In 1921 the Forest Service made two recommendations to aid eastern forestry. It recommended acquisition of 3 million acres of important watersheds lands in the Eastern States—to be added to the national forests that had been established under the Weeks Act of 1911.

These watershed areas would increase national forest acreage in the East significantly, allowing the Forest Service to further implement its research and management plans. The Allegheny, White Mountain, and Green Mountain National Forests of the Northeast, expanded during the 1920s under the Weeks Act, later provided experimental forests and sample-plot sites for the Northeastern and Allegheny Forest Experiment Stations.

In 1920 and 1921 the Forest Service also recommended creation of a nationwide forest-research system consisting of one forest experiment station for each of the 12 major timber regions of the United States. The Forest Service recognized that research had to focus on conditions unique to the forest types of each region. Completion of this system would mean that four additional stations would be necessary to serve the Northeastern States, the Allegheny Mountain or Middle Atlantic Region, the Lake States, and the California Region. These stations were established in the 1920s.

CREATION OF EXPERIMENT STATIONS IN THE NORTHEAST

The Original Northeastern Station

Congress authorized establishment of the Northeastern Forest Experiment Station in June 1923. Its domain was to include New England and New York, a seven-state area dominated by pine, spruce, fir, and hardwood forests.

The legislation was sponsored by Senators Henry Cabot Lodge of Massachusetts and Henry Wilder Keyes of New Hampshire and Representative Bertrand Hollis Snell of New York. Strong support came from the timberland owners and forest-product industries of the region. One of the most vigorous proponents for establishment of the Station was Samuel T. Dana, then Forest commissioner of Maine.

A native of Maine, Dana went to Bowdoin College, took a master's degree in forestry at Yale in 1907 and then entered the U.S. Forest Service. One of his first jobs, in the Office of Silvics, was to select a site for the first federal forest experiment station, established near Flagstaff, Arizona. He later made the survey that resulted in the choice of Asheville, North Carolina, as the site of the Appalachian Forest Experiment Station.

From 1910 to 1915 he served as assistant chief of the Forest Service's Office of Forest Investigations at Washington, one of the predecessors of the Branch of Research. After an absence due to war duties, he became assistant chief of the new Branch of Research.

Dana knew the Northeast. In 1910 he had completed a study of ghost towns of the East. By tracing the history of these communities, he found example after example of towns that had depended upon the lumber industry for their existence but had virtually disappeared after the timber had run out.

In 1921, Dana left the Forest Service to become Forest Commissioner of Maine.

To select a site for the proposed Northeastern Station, the Forest Service called on Dana. By then the Forest Service had developed criteria for locating an experiment station. It

preferred a place centrally located in its region, convenient to transportation, and close to library and laboratory facilities. A college or university campus seemed ideal.

The choice narrowed down to the Massachusetts Agricultural College at Amherst, Massachusetts (now the University of Massachusetts). The decision to locate there was due partly to the efforts of Frank A. Waugh, head of the Department of Horticulture, who had previously worked for the Forest Service; he had made the first official inventory of recreational resources of the national forests.¹

Sam Dana was appointed first director of the Station. Nobody could have been better qualified for the job.

The Station had offices in the College's French Hall and Clark Hall. These quarters were very crowded in winter, when office work took precedence over field work.

Samuel T. Dana.



OLD NORTHEASTERN FOREST EXPERIMENT STATION (1923 - 1945)



HEADQUARTERS:

- 1 Amherst, Mass. (1923-1932)
- 2 New Haven, Conn. (1932-1942)



EXPERIMENTAL FORESTS:

- 3 Massabesic-Alfred, Me. (1936-Present)
- 4 Gale River-Bethlehem, N.H. (1928-1942)
- 5 Bartlett-Bartlett, N.H. (1928-Present)
- 6 Finch Pruyn-Newcomb, N.Y. (1933-1961)
- 7 Chenango-Smyrna, N.Y. (1933-1942)
- 8 Lawrence-Hopkins-Williamstown, Mass. (1935-1968)



The original Northeastern Forest Experiment Station's area of responsibility and its research facilities (1923-45).

ALLEGHENY FOREST EXPERIMENT STATION (1927-1945)



HEADQUARTERS:

1 Philadelphia, Pa. (1927-1945)

2 Kingston, Pa. (1942-Present)

3 Laurel, Md. (1939-1961)

FIELD RESEARCH HEADQUARTERS:

EXPERIMENTAL FORESTS:

- 4 Camp Ockanikron-Medford, N.J. (1928-1934)
- 5 Lebanon-New Lisbon, N.J. (1934-Present)
- 6 Standing Stone-Manor Hill, Pa. (1938-1948)
- 7 Kane-Kane, Pa. (1932-Present)
- 8 Beltsville-Laurel, Md. (1939-1961)
- 9 Eastern Shore, Parsonsburg, Md. (1938-1945)
- 10 Massabesic-Alfred, Me. (1936-Present)*
- 11 Bartlett-Bartlett, N.H. (1928-Present)*
- 12 Finch Pruyne-Newcomb, N.Y. (1933-1961)*
- 13 Lawrence Hopkins-Williamstown, Mass. (1935-1968)*



(* Held by Allegheny Station as "caretaker" for Old Northeastern Station, being phased out.)

The Allegheny Forest Experiment Station's area of responsibility and its research facilities (1927-45).

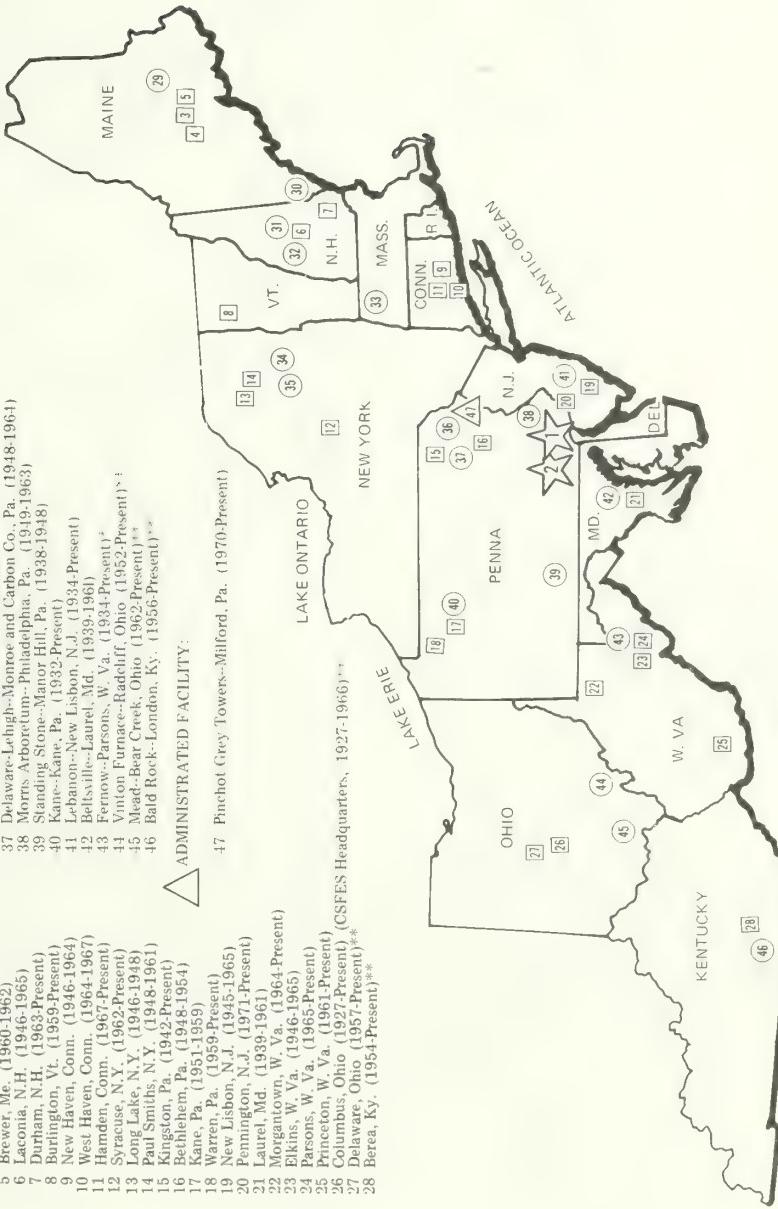
NORTHEASTERN FOREST EXPERIMENT STATION (1945 - Present)



- HEADQUARTERS:
 - 1 Philadelphia, Pa. (1945-1948)
 - 2 Upper Darby, Pa. (1948-Present)
 - FIELD RESEARCH HEADQUARTERS:
 - 3 Orono, Me. (1945-1963-Present)
 - 4 Bangor, Me. (1946-1959)
 - 5 Brewer, Me. (1960-1962)
 - 6 Laconia, N.H. (1946-1965)
 - 7 Durham, N.H. (1963-Present)
 - 8 Burlington, Vt. (1939-Present)
 - 9 New Haven, Conn. (1946-1964)
 - 10 West Haven, Conn. (1946-1967)
 - 11 Hamden, Conn. (1967-Present)
 - 12 Syracuse, N.Y. (1962-Present)
 - 13 Long Lake, N.Y. (1946-1948)
 - 14 Paul Smiths, N.Y. (1946-1961)
 - 15 Kingston, Pa. (1942-Present)
 - 16 Bethlehem, Pa. (1948-1954)
 - 17 Kane, Pa. (1951-1959)
 - 18 Warren, Pa. (1959-Present)
 - 19 New Lisbon, N.J. (1945-1965)
 - 20 Pennington, N.J. (1971-Present)
 - 21 Laurel, Md. (1939-1961)
 - 22 Morgantown, W. Va. (1964-Present)
 - 23 Elkins, W. Va. (1946-1965)
 - 24 Parsons, W. Va. (1965-Present)
 - 25 Princeton, W. Va. (1961-Present)
 - 26 Columbus, Ohio (1927-Present)*
 - 27 Delaware, Ohio (1957-Present)**
 - 28 Berea, Ky. (1954-Present)**



- ADMINISTRATED FACILITY:
 - 29 Penobscot-Bridgton, Me. (1950-Present)
 - 30 Massabesic-Alfred, Me. (1936-Present)
 - 31 Bartlett-Bartlett, N.H. (1928-Present)
 - 32 Hubbard Brook-West Thornton, N.H. (1955-Present)
 - 33 Lawrence Hopkins-Williamsburg, Mass. (1935-1968)
 - 34 Paul Smiths-Paul Smiths, N.Y. (1948-1961)
 - 35 Finch Pynwy-Newcomb, N.Y. (1933-1961)
 - 36 Pocono-Gouldsboro, Pa. (1938-1959)
 - 37 Delaware-Lough-Monroe and Carbon Co., Pa. (1948-1964)
 - 38 Morris Arboretum-Philadelphia, Pa. (1948-1963)
 - 39 Standing Stone-Mano Hill, Pa. (1949-1948)
 - 40 Kane-Kane, Pa. (1932-Present)
 - 41 Lebanon-New Lisbon, N.J. (1934-Present)
 - 42 Beltsville-Laurel, Md. (1939-1961)
 - 43 Fernow-Parsons, W. Va. (1934-Present)*
 - 44 Vinton Furnace-Radolf, Ohio (1952-Present)*
 - 45 Mad-Bar Creek, Ohio (1962-Present)**
 - 46 Bald Rock-London, Ky. (1936-Present)**



* Acquired from the Appalachian Forest Experiment Station during the reorganization of 1945

** Acquired from the Central States Forest Experiment Station during the reorganization of 1966

The Present Northeastern Forest Experiment Station's area of responsibility and its research facilities.

The original scientific staff was small, consisting of C. Edward Behre and Marinus Westveld, associate silviculturists, and Walter H. Meyer, forestry assistant.

In 1927, Dana left the Station to become the first dean of the School of Forestry and Conservation at the University of Michigan.

John S. Boyce became the new director. Boyce, a graduate of the University of Nebraska, with master of forestry and Ph.D. degrees from Stanford University, had served a couple of years with the Forest Service, then joined the Bureau of Plant Industry, where he served 15 years as a pathologist. His term as director was brief, for he left the Station in 1929 to become professor of pathology at the Yale University School of Forestry.

John S. Boyce.



The Allegheny Station

Legislation to establish the Allegheny Forest Experiment Station was passed by Congress in 1927. This Station was created to tackle the forestry-research problems of the Middle Atlantic States: New Jersey, Pennsylvania, Maryland, and Delaware.

Reginald D. Forbes was appointed director. Forbes, who graduated from Williams College

Reginald D. Forbes.



and took his master's degree in forestry at Yale, had field, research, and administrative experience in forestry. He had served 3 years with the U.S. Forest Service as forest assistant on the Tonto, Carson, and Pisgah National Forests; and 2 years as Assistant State Forester of New Jersey. He was the first State Forester of Louisiana (1917-21) and the first director of the Southern Forest Experiment Station (1921-27).

His first tasks were to establish a headquarters, recruit a staff, find research facilities, and get a research program started. After touring the four-state region by train (automobile travel was slow and inconvenient in those days) to consider various locations for a headquarters, Forbes and Chief Forester Clapp decided on Philadelphia, then railroad center for the region.

The University of Pennsylvania offered the use of a three-story building on its campus and erected a greenhouse on nearby University property for the Station and its collabor-

ators from the Bureau of Plant Industry. The university atmosphere stimulated the Station staff's early interest in fundamental research, manifest in A. B. Hatch's study of mycorrhizae, in staff studies of virgin forests, and in systematic meteorological and phenological observations.

The initial staff was small: silviculturists Ashbel F. Hough, Harold J. Lutz, G. Luther Schnur, O. M. Wood, A. B. Hatch, and Harold F. Morey. Within a few years, Carl Ostrom, J. E. Hetzel, and William Mollenhauer, Jr., had joined the staff. The Bureau of Plant Industry assigned K. D. Doak, L. W. R. Jackson, and Bailey Sleeth to the Station as collaborators. Cooperation later came also from the Bureau of Entomology.

The Station's first research facility was a tract of 340 acres near Medford, New Jersey, lent by the Y.M.C.A.'s Camp Ockanickon. The Station's annual budget at this time was \$30,000. By mid-1928, the Station had field work under way. Within a few years, field headquarters were moved to New Lisbon, New Jersey, where the New Jersey Department of Conservation and Development set aside a tract on Lebanon State Forest for permanent use by the Station. Grants of WPA funds enabled the Station to erect an office building and field quarters.

In 1930, the 2,000-acre Kane Experimental Forest was established in northwestern Pennsylvania, on land provided by the Allegheny National Forest. Here too, WPA funding made it possible to build a headquarters office and three dwellings. One hundred acres of the experimental forest were to be preserved for studying the natural forest cycles. The forest also included "thoroughly wrecked cut-over land" and timbered areas suitable for the production of sawlogs and chemical wood (for charcoal and chemical derivatives).

The Allegheny National Forest also made available to the Station an area called Heart's Content, 20 acres of virgin forest dominated by white pines 275 years old. Through promotion by the Pennsylvania Forestry Association, the Federal Government in 1934 purchased the 3,100-acre Tionesta Natural Area, a forest of virgin hemlock and hardwoods on nearby Tionesta Creek, for use in Station research.

About 1937, two other research areas were made available through Department of Agriculture depression programs: the Standing Stone Experimental Forest in central Pennsylvania near State College, and the Beltsville Experimental Forest in Maryland near University Park. The WPA provided funds for buildings on both.



Station research foresters examine one of the early clearcut plots in northern hardwoods on the Bartlett Experimental Forest in New Hampshire. September 1937.

PUBLIC SUPPORT AND GUIDANCE: THE ADVISORY COUNCILS

One of the first concerns of the new forest experiment stations in the Northeast was their relationship with other forestry interests—the universities and colleges, the state forestry agencies, the agricultural experiment stations, the forest-product industries, and the forest-land owners. To fit Forest Service research into the pattern of pre-existing activities called for skilled diplomacy.

Dana devoted much time and attention to public relations, making contact with research groups and timberland owners. He has said that one of his most useful activities in those early years was in establishing a rapport with the region's agricultural experiment stations. The avenues of communication he opened up helped greatly in the administration of the Station.

To gain the support and cooperation of the diverse forestry interests in the region, and to coordinate the Station research program with their activities, Dana organized the Northeastern Forest Research Advisory Council. It held its first meeting on 3 April 1924 in Memorial Hall on the Massachusetts Agricultural College campus at Amherst.

The scope and purpose of the advisory council were defined early. At its first meeting, the Northeastern council decided "that the usefulness of such a committee might be greatly increased by making it an advisory body not only to the Forest Experiment Station, but to other investigators as well."

Such a wider scope, it was believed, would facilitate the coordination of current and future forest research, encourage increased research, and concentrate attention on the problems of greatest scientific and practical importance. Council decisions could not be made mandatory, but would perhaps command sufficient respect to secure better coordination of forest research in the region than had existed before.

The advisory council idea was copied by many other Forest Service experiment stations. One of the first was the new Allegheny Station, where Director Forbes, with the help of Jacob G. Lipman, director of the New Jersey Agricultural Experiment Station at

New Brunswick, set up what he calls "an infinitely loyal advisory council" to get cooperation from state, industrial, and private forestry interests in the region. It held its first meeting on 27 March 1929.

Both the Northeastern and Allegheny Councils functioned almost as envisioned by Dana. Each Council consisted of 12 to 15 representatives of colleges and universities, museums and other private institutions, state and federal experiment stations, state executive agencies, wood-product industries, land-owners, and a few public-spirited individuals interested in forestry. Membership terms of 4 years were staggered to maintain continuity.

Year after year the councils met to review the Stations' research programs and to give their recommendations to the Station directors. The councils also advised the state legislatures and the U.S. Congress of the legislative and budgetary needs for forestry research in the region. The councils were firm supporters of the Forest Service's efforts to obtain passage of the McSweeney-McNary Act of 1928.

When the two experiment stations were merged during World War II, the two advisory councils were combined. This consolidated council was especially effective in the post-war 1940s in persuading the Congress to greatly expand Forest Service research in the Northeast.

In 1963 the Northeastern Forest Research Advisory Council was renamed the Northeastern Forestry Research Advisory Committee. Its purposes did not change.

The Advisory Committee has continued to the present as a strong and helpful complement to the Experiment Station's research effort. It has helped the Station respond to the needs of the region and has improved relations between the Forest Service and private owners. It has helped to promote increased appropriations for research. It has played a role in getting research results put into practice by forest-related industries and landowners.

THE FIRST RESEARCH PROJECTS

The Northeastern Station

Dana and his colleagues from the beginning saw a need to focus on the most urgent problems. Their first priority was to maintain and strengthen the forest industries of New England and New York so they could provide the lumber needed for present and future demands. Research in the early years focused on the timber-management problems: silviculture, mensuration, and protection from fire, insects, and diseases.

The character of research projects in the 1920s was determined by the management problems in the major forest areas of the region.

In northern New England and New York the spruce-fir and northern hardwood types prevailed. Sparsely settled wild lands contained the bulk of merchantable timber in the region. The hardwood industry suffered from lack of markets, and the softwood lumber industry had given way in large part to pulpwood production, which required accelerated growing of spruce.

A densely populated industrial area, comprising all of Connecticut and Rhode Island, southeastern New York, and most of Massachusetts presented its own set of forestry problems. Here chestnut had once been an important commercial species; but the blight had killed the chestnut, until white pine (always important and dominant in some areas), oaks, and other species predominated. New growth was being cut for portable sawmills, and fires took their toll every year. This area had great potential for recreational and watershed uses.

A third kind of forest zone consisted of scattered farm woodlots and old-field forests. These were areas where abandoned farms had reverted to forest and had been subjected to repeated cuttings. Small inferior growth was common. Because ownership was fragmented, research in forest economics was as important here as timber-management research. Small wood industries existed here, and transportation facilities were available.

In the 1920s, the Station concentrated on the spruce-fir and hardwood forests of the

northern wild lands. The spruce-fir of northern New England supplied most of the pulpwood produced in the Northeast. In the 1920s, the Station's silvicultural research on spruce-fir was mainly the work of Meyer and Westveld. Meyer compiled yield tables for even-aged stands of spruce-fir. Westveld's work, begun in 1923 and continued until his retirement, focused on the management of spruce and balsam fir. Through the study of cutting methods, natural reproduction, slash disposal, and cultural methods, Westveld sought ways of obtaining higher pulpwood yields. By 1935 research in the management of spruce indicated that selective cutting usually was, silviculturally, the best way to harvest spruce.

Two experimental forests on the White Mountain National Forest were used for research in spruce-fir and northern hardwoods. One was the 3,350-acre Gale River Forest in New Hampshire, a burnt-over tract—half flat, half slope—of spruce and balsam fir, with hardwoods and some pine. The 5,100-acre Bartlett Experimental Forest at Bartlett, New Hampshire, was ideal for experiments with northern hardwoods. The Station also used the Massachusetts Agricultural College's Mt. Toby Forest and the Harvard Forest at Petersham, Massachusetts.

Several forest-fire studies were made by the Station in the late 1920s and 1930s. Dana compiled and analyzed fire tables. Paul W. Stickel worked for several years on fire weather research, a field pioneered by the Northern Rocky Mountain Experiment Station. Early fire studies were made mainly in the northern portion of the region.

Insect research was important at the Station from the beginning. Of the insect infestations that plagued the Northeast, the greatest and most persistent threat was the spruce budworm. H. B. Peirson, assigned to the Station as a cooperator by the Maine Forest Service, was one of the first to investigate means to stem the epidemic that threatened spruce-fir forests in both New England and Canada. The Station and the Bureau of Entomology also cooperated in the 1920s on research aimed at at-

tacking the white-pine weevil infestation, but with little success.

Few of the Station's cooperative projects proved as rewarding as that carried on, from 1925 into the 1930s, by Perley Spaulding, a forest pathologist from the Bureau of Plant Industry who investigated the fungi involved in the decay of slash. In the West, it was generally necessary to dispose of logging slash by burning or other means to reduce the fire hazard, and many assumed that this would be a necessary or desirable practice in the East as well. Spaulding's work demonstrated that hardwood slash in the Northeast would decay naturally in a reasonable length of time; thus the bother and expense of slash disposal could be avoided. Spaulding also did some of the basic research on white-pine blister rust, and he studied a number of other tree diseases.

Another early project of note was Behre's development of universal volume and taper tables, based on a formula that would give volume for any species from taper and certain other measurements. A modification of Behre's system was adopted in the South.

The Allegheny Station

In its early research, the Allegheny Station followed a pattern similar to that of the Northeastern Station. To increase the timber available for local utilization, the Station emphasized silvicultural research in the dominant lumber-producing forest areas.

In the Allegheny region too, the character of the research projects was determined by the management problems of the different types of forest in the region. There were sparsely settled inland areas of hardwood forest; coastal oak-pine forests; and forest lands associated with the heavily settled metropolitan areas in Pennsylvania, Maryland, and New Jersey.

From 1927 to 1929 the Station staff studied regional problems, evaluating needs and starting research on the most pressing problems. The staff estimated that Delaware, Maryland, New Jersey, and Pennsylvania contained 13 percent of the United States population but only 3.8 percent of the forest area. The region's lumber consumption outran production eight to one.

The staff calculated that, with intensive management, the area could eventually supply itself. To do so would require the production of 176 board feet per acre, and most of the land was believed fertile enough to produce at this rate. However, because the forests of these four states had suffered severely from cutting and fires, it might take more than three-quarters of a century to restore them.

The Allegheny Station's research began in New Jersey, on the Ockanickon tract. L. L. Lee of the New Jersey Agricultural Experiment Station mapped the soils of the area. O. M. Wood of the Station staff studied the various forest types of southern New Jersey.

In the summer of 1928 the entire staff joined in a study of virgin forest at Heart's Content on the Allegheny Plateau in Pennsylvania. Forest soils were studied intensively. Forest types were studied: in those days forest types had not yet been thoroughly classified. By early 1930, the research of the Station, plus work by the Allegheny Section of the Society of American Foresters, had produced a system of seventeen forest types. Late the same year the number was reduced to fourteen.

Meanwhile, Station scientists were acquiring more sophisticated research skills. Luther Schnur was in Washington studying mensuration and statistics. Later, Clement Mesavage, at the Station's center for research in the Anthracite Region, at Kingston, Pennsylvania, studied mensuration under James Girard (who had cruised the Tionesta Natural Area before its purchase for the Station). Mesavage later served at the Southern Station and became a leading Forest Service mensurationalist.

The largest project carried on by the Allegheny Experiment Station from 1927 through the 1930s, consuming at times two-thirds of the Station's annual budget, was on the silviculture and management of the commercially important Allegheny hardwoods.

Here Hough began his career-long study of the Allegheny Plateau forests, pioneering research on the ecology, silviculture, and management of the Allegheny hardwoods.

By 1930 the Station had differentiated the main subtypes of this Allegheny hardwood-hemlock forest and had established tentative ecological relationships, the requirements of the principal species for light, moisture, tem-

perature, and other environmental conditions had been studied, and growth habits of the principal species had been described. The reproductive habits, except those of hemlock, were well understood.

As late as 1929 silviculturists generally thought that this hardwood type included white pine. However, the studies on the old-growth Heart's Content preserve revealed that white pine does not reproduce under forest cover and cannot be included in the northern hardwood forest type. Cutting or natural catastrophes such as fire, disease, or insect infestation are required for the growth of white pine even-aged stands. Early research on the northern hardwood-hemlock type—which includes hemlock, yellow birch, beech, sugar maple, red maple, and black cherry—seemed to show that selective cutting was preferable to clearcutting.

The Station had three other dominant projects during these early years. Forest management for southern New Jersey was studied with the hope that forest lands there could be restored to greater productivity. The principal tree species of the Jersey coastal plain were chestnut, white, and black oaks, and pitch

and shortleaf pines. All these except shortleaf pine sprout from the stump, so they persist after cuttings and fires, although they are progressively inferior in subsequent generations.

A way had to be found to supplement sprout growth with trees grown from seed. Considerable data were gathered on the relative values of different oak and pine species, the use of fire to increase the production of pine, and the characteristics of sprouting. Many data were gathered on seed production and germination and the detrimental effects of animals, birds, root rots, and injuries above ground.

The Station also accumulated information about the growth of loblolly pine in eastern Maryland. Effects of stand density and age on the diameter distribution of loblolly pine were measured on 73 sample plots that had been established in 1906 by the Maryland Forest Service on private land in Maryland.

One outstanding work in these early years was on mycorrhiza, a symbiotic or parasitic association between soil fungi and tree roots, found on practically every species of tree and woody plant in the Allegheny territory.



Marinus Westveld (left) and Director Behre discuss a spruce-fir pulpwood cutting on experimental plots on the Gale River Experimental Forest. September 1937.

On the Dartmouth Trail thinning plots in a 130-year-old spruce stand on the White Mountain National Forest. The stand as thinned from below in 1933. September 1937.



THE DEPRESSION YEARS 1929 TO 1940

The Depression brought hard times to the Northeastern and Allegheny Forest Experiment Stations. Regular funding was inadequate for the work to be done. Both Stations trimmed and tightened their programs to focus their efforts on the most urgent problems. Economic forestry problems received primary consideration.

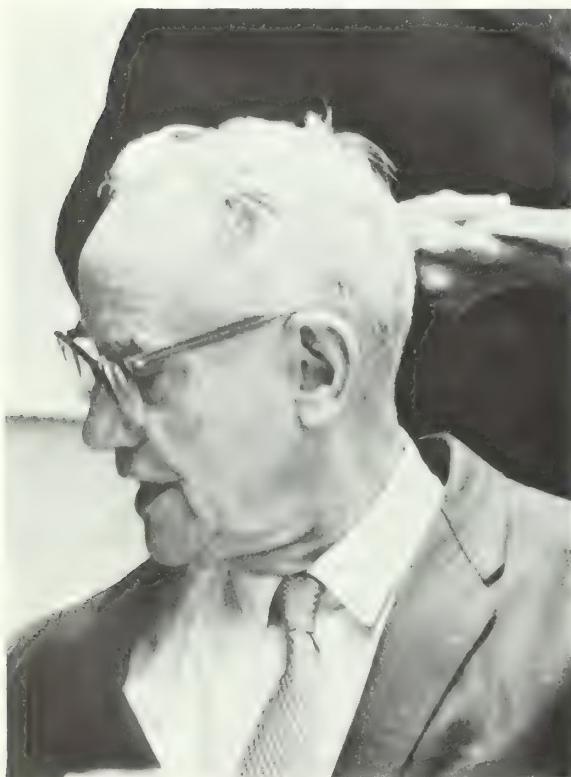
In 1929 Behre succeeded Boyce as director of the Northeastern Station. A graduate of the Yale School of Forestry, Behre had served at the University of Idaho as associate professor of lumbering, specializing in mensuration. He had joined the Station at its beginning, as an associate silviculturist.

By 1930 the scientific staff had increased to eight. Westveld was doing research in silviculture, Stickel in fire, and Victor S. Jensen in mensuration. In addition to them, the Station provided office space and facilities for three

scientists from cooperating agencies: H. J. MacAloney of the Bureau of Entomology, doing research on forest insects; Perley Spaulding of the Bureau of Plant Industry, working in forest pathology; and J. Paul Miller, a forest biologist from the Biological Survey.

In 1932 the Northeastern Station moved its headquarters from Amherst to New Haven, Connecticut. At that time the Massachusetts Agricultural College was growing and urged the Station to find other quarters. Henry S. Graves, dean of the College of Forestry at Yale University, told Behre that a fine property on Prospect Street had been offered to the University but that the trustees were hesitant about accepting it. "This is not going to be a white elephant," Dean Graves told them; "this is just a challenge to your imagination." So the Northeastern Station moved into Farnum House in New Haven.

C. Edward Behre.



Money Problems

Upon his appointment, Behre worked to expand the Station's program. He pointed out that the Northeastern Station had not received the "substantially enlarged appropriations" that most other Forest Service experiment stations had received. The result was the narrowly prescribed lines of the Station's investigations, most of them oriented toward spruce silviculture and management. Even this limited program, Behre suggested, suffered from lack of coordinated studies by entomologists, pathologists, and biologists. He cited the minimal development of branch stations as a further weakness.

The McSweeney-McNary Forest Research Act of 1928 authorized expanded funding. By 1930, however, the Northeastern Station had not benefited from the increased appropriations stimulated by this act. Behre resolved to seek, under the act, support sufficient "to meet the needs of the Region and keep abreast of development at other stations."

The Allegheny Station had fared little better. Its initial budget of \$30,000 in 1928 increased to only \$30,845 in 1931, although in

1930 a \$10,000 appropriation in accordance with the McSweeney-McNary Act authorization had enabled the Bureau of Plant Industry to assign two pathologists to the Station.

Despite the McSweeney-McNary Act, appropriations did not increase appreciably during the 1930s. The depression and the economy cuts of 1933 and 1934 reduced the Northeastern Station's regular budget one-fourth and the Allegheny Station's one-third. The depression was not, however, totally responsible for the funding problems that plagued the two Stations.

Emergency appropriations of the 1930s, although unpredictable, did much to offset the financial troubles. Relief funds peaked between 1936 and 1939, then dwindled. The Northeastern Station's annual report for 1940 noted that the previous decade had been an era of "dwindling allotments." "Faced with successive reductions in allotments," in a period during which it "had been called upon to widen the scope of its activities", the staff found it "necessary to re-evaluate and concentrate its research efforts."

In 1939 the Allegheny Station's budget was smaller than that of the Northeastern Station. Hough lamented the reduction of research to timber-management problems, ignoring the forest economic, recreational, wildlife, and watershed needs of the region.

There were reasons for this. First, non-federal expenditures for forest research were higher in the Northeast than in any other region, making federal involvement less urgent.

Second, the forestry problems of the Northeastern and Allegheny regions seemed to be less acute than those elsewhere. In forest types that had been exploited in relatively recent years, such as spruce-fir and northern hardwoods, the forests usually recovered after heavy cutting. And in types that had been utilized severely since Colonial times, such as the forests of Connecticut and New Jersey, forest conditions had improved in many areas—mainly because the availability of coal had lessened the need for wood for fuel.

Third, forest economic conditions seemed less dire in the East than in other regions that were experiencing timber shortages for the first time. The people of the Lake States and the South felt, during the 1920s, the effects

of the migratory character of the lumber industry. Local depression was new and severe. The New England and Middle Atlantic States had already gone through this stage, in some areas as early as the 1700s. Industrialization and agriculture had grown up, stabilizing local communities. Communities that had depended upon departed timber industries had either found new economic bases or had become ghost towns.

Fourth, the percentage of America's total lumber consumption that the Northeastern and Middle Atlantic States could supply, even under ideal conditions, was smaller than the real and potential output of the South or the Pacific Northwest. Problems of trespass, fire, grazing, and watersheds did not demand sizable federal appropriations in the East, as they did in the West—and the northeastern states had sizable budgets for fire prevention and protection.

Land-ownership patterns complicated the problems of timber management in the Northeast. More than two-thirds of all commercial forest land in New England and the Middle Atlantic States was owned in tracts of less than 5,000 acres. Federal investments in research for Northeastern forests could not be counted upon to yield returns as large as similar investments in southern pine or Douglas-fir forests.

Appropriations for the Station waned in the 1930s. The seriousness of the funding decline in an era when problems were increasing had been hidden by federal and state emergency relief money and manpower as well as by funds for the flood-control survey begun in 1936. From 1937 to 1940, Civilian Conservation Corps allotments decreased to almost nothing. In 1941 the Work Projects Administration program was curtailed, and the flood-control survey was transferred to the Allegheny Station.

Steps Ahead

Despite financial handicaps, the two Stations accomplished a great deal during the 1930s. Declining values made land available to the Forest Service either through donation or at a very low price. National forests and experimental forests were expanded.

By 1936 the Northeastern Station had added four new tracts to the two it had previously established (the Gale River and Bartlett Experimental Forests). The Massabesic Experimental Forest, 2,500 acres in Maine, was purchased from Bates College by the National Forest Reservation Commission for experiments in white pine. The Lawrence Hopkins Memorial Experimental Forest, 1,635 acres near Williamstown, Massachusetts, was a gift from Williams College. A forest of about 600 acres of spruce and hardwoods in the Adirondack Mountains was deeded by Finch Pruyn and Company to Cornell University, which in turn allowed its use by the Station under co-operative agreement. The Chenango Experimental Forest, 534 acres of open farmland in New York, was made available by the State of New York for reforestation research.

By this time the Allegheny Station had acquired three other experimental forests through the Resettlement Administration: the Standing Stone Forest of 1,800 acres in central Pennsylvania; a tract on the Western Shore of Maryland; and 1,000 acres of pine on the Eastern Shore of Maryland.

In the depression decade the two Stations received emergency relief funds and labor. Between 1935 and 1940, the Emergency Relief Administration and the Emergency Conservation Work funneled \$30,000 to \$80,000 a year into the Northeastern Station's budget. The Allegheny Station received \$20,000 to \$30,000 per year.

Restrictions on the use of these funds and their uncertain duration meant they could not be used to employ highly trained scientific personnel or to carry on long-term projects. Clerks, draftsmen, stenographers, and laborers were hired instead. These new employees permitted rapid development of sample plots and experimental forests. Capital improvements included the construction of offices and living quarters, roads and fire lines, and electric, sewage, and water plants. Sample plots were marked and trees were cut, pruned, or weeded. With New Deal funds, inventory cruises were made on the experimental forests and records of precipitation and other environmental data were kept.

The Farm Woodlots

During the depression decade, the scope of the Northeastern Station's activities shifted to include forest economics—forest taxation, land use, and forest-fire insurance. The Station ventured into a new economic zone: the farm woodlot areas, predominantly of the white pine and hardwood types.

Economic problems caused by fragmentation of ownership were major obstacles to good forestry on these woodlot lands. There was a variety of small industries, producing box boards, maple sugar, cooperage, and native woodcrafts. But these industries were seldom profitable for the timber grower. Farmers often disposed of the products of their small woodlots unwisely, selling their timber for fuelwood or to inefficient, low-paying portable sawmills. The channel of trade from stump to market needed improvement.

Although the problems of the farm woodlot owner had existed throughout the 20th century, funding for research in this area reached its high point in the 1930s. Behre believes that the sudden spurt in economic research in the mid-1930s was part of the gradual expansion of the Station's programs and not a response to the depression.

There is no question that the Station staff had been aware of the economic troubles of small woodlot owners before the 1930s. Economic research, however, was particularly relevant to the harsh financial realities of the 1930s. In the rural areas of the Northeast, mortgage debts were increasing, relief rates were rising, per-capita income was decreasing, and entire communities were declining. Federal appropriations for economic research in farm forestry were not provided until the Norris-Doxey Cooperative Farm Forestry Act of 1937 and the Bankhead-Jones Farm Tenant Act of 1937.

The Northeastern Station's farm-forestry research program embodied the Forest Service's concept of regional experiment stations as local research coordinators. Even in the early 1930s, the Station coordinated its farm forestry program with state and county planning efforts. The Norris-Doxey Act accelerated this trend by authorizing cooperation between federal and state forestry agencies to

aid farmers in managing their woodlots. The Station participated in this program by conducting demonstration projects. The Station's responsiveness to forest problems of local farmers included assistance to farm cooperatives.

One of the most important sources of the Station's federal funding for economic studies during the 1930s was the Bankhead-Jones Act. This legislation established the Farm Security Administration, which in turn financed loans to cooperatives.

The Otsego Cooperative

The cooperative movement was gaining strength at this time, and in some activities cooperatives had been very successful. The Northeastern Station staff believed that the answer to the economic problems of the small woodlot owner might "lie in cooperative logging and milling facilities as well as primary manufacturing facilities . . ." Such control might enable the timber grower—not just the manufacturer—to profit.

The Otsego Forest Products Cooperative Association was established in 1936 at Cooperstown, New York. Its purpose was to help local woodlot owners manage their forest land, harvest their timber, and sell their forest products at a profit.

The Otsego Cooperative grew out of the interest of local people, encouraged by the Northeastern Station's staff, which hoped to serve as a catalyst for local action. Local interest came from many sources during 1935 and 1936, such as the traveling grocery-store proprietor who promoted the Cooperative and later became its manager.

The first 2 years were spent obtaining local support. Eleanor Roosevelt facilitated a federal loan from the Farm Security Administration. Through a small research unit established in Cooperstown in 1936, directed by Charles R. Lockard, the Northeastern Station supplied technical and administrative assistance to the Cooperative and administered the federal loan. M. B. Dickerman, specialist in the economics of private forestry, left the Station in 1940 to manage the new venture for a few years.

The Cooperative built a sawmill for processing forest products, inaugurated a program of

forest management, established sales outlets, and developed membership. Despite financial difficulties, the Cooperative had 765 members by 1942 and seemed to be going strong.

Forest Economics and The Anthracite Region

The Allegheny Station also ventured into forest economics in the 1930s. Aware of the social and economic troubles of its region, the staff proposed studies of the dollars-and-cents value of the forests for recreation and watershed protection, the marketing problems of the small wood operators, and the opportunities for forest employment in the coal-producing regions.

In 1939, the Station obtained \$18,000 for research on forest employment in the Anthracite Region of Pennsylvania. Prodded by Stanley Mesavage, a self-taught forester, the Wyoming Valley Chamber of Commerce interested Senator Joseph Guffey in the needs of the region.



Ashbel F. Hough measures a 36-inch hemlock in the Tionesta Scenic Area, a virgin hemlock-beech forest in the Allegheny National Forest. April 1934.

In the 15 counties of the Anthracite Region, the total population of 1,600,000 was dependent upon coal. From 1917 to 1940 coal production had decreased by half, and unemployed miners numbered 50,000. There was little likelihood of their reemployment in the mines, and state and county authorities were unable to find suitable relief work projects to effectively combat the serious level of unemployment.

The Station's goal was to use this labor to build up the 2,877,000 acres of depleted forest land in the region to provide raw materials for permanent wood-using industries and esthetic surroundings attractive to recreationists. A plan of action was necessary to bring these two resources—men and trees—together to create a stable forest economy. The Station's first recommendations were for public acquisition of forest lands and a resource inventory of the Region.

The onslaught of World War II halted the project. War-related research needs took precedence over economic research. Unemployment declined in the Anthracite Region.

Genetics Research Begun

The offer of the Oxford Paper Company to transfer its thousands of hybrids and all records of its poplar breeding project (started in 1924) to the Forest Service led to an appropriation for initiation of the forest genetics project at the Northeastern Station in 1936. This Congressional action resulted from the efforts of Director Behre; the late Dr. C. C. Heritage, director of research at Oxford Paper Company; and the late Dr. A. B. Stout, director of laboratories at the New York Botanical Garden.

The appropriation provided not only for continuation of the research with hybrid poplars, but also for genetic research on the improvement of other important northeastern species. The additional funds were sufficient to finance a staff of three professionals—Ernst J. Schreiner, project supervisor, Albert G. Snow, Jr., and John W. Duffield—two subprofessionals, and a clerk-stenographer. PWA and CCC labor was available for routine laboratory and field work.

Drought and Floods

In the 1930's, the need for research in watershed management became apparent, particularly at the Allegheny Station. The Allegheny territory is characterized by three centers of extreme population concentration—Philadelphia, north Jersey, and Baltimore. The task of supplying water for municipal use was stupendous. Little of this supply came from the large rivers, because they were insufficient and polluted. Underground waters were not considered a viable alternative. Populated areas had to draw upon the distant headwaters of major and minor streams.

A severe drought hit the major eastern cities in 1930. Scientists at the Allegheny Station recommended research into the impact of vegetation on streamflow, especially the flow into reservoirs under construction. Some watersheds would have to be planted. The Station believed it would need at least four men for watershed management research.

More disasters occurred before federal appropriations for surveys or research were made available. In the spring of 1936 the flooding of all the major rivers of the Northeast caused an estimated damage of \$500 million dollars and uncalculated human suffering. In 1937 another flood, originating in the Allegheny region, ravaged the Ohio Valley. The Flood Control Acts of 1936 and later years authorized the Department of Agriculture, in cooperation with the Army Corps of Engineers, to survey the watersheds of the principal streams of the Northeast to ascertain whether or not the condition of the watershed vegetation had contributed to the floods.

Between 1937 and 1941 the Allegheny Station had been given primary responsibility for the Passaic and Pequest River surveys and the Connecticut River survey and participated in field work on the Allegheny River, the upper Susquehanna River, and Solomon Creek. Arthur Bevan was in charge of these surveys. In 1940 the Allegheny Station took over the Northeastern Station's small flood-control survey program.

The Connecticut study revealed techniques of agricultural land management that could be used to alleviate the conditions that produce flood runoff and erosion. The Station found

that forest soils have a significant capacity to take up water rapidly during periods of excessive rainfall and to give it off slowly. The Station's participation in the flood-control surveys was curtailed in 1942 because of the war. Responsibility for these surveys was transferred from research to the Regional Office in 1953.

The Hurricane of 1938

The catastrophic hurricane of September 1938, which severely damaged a wide swath across New England, swept the Northeastern Station into 2 years of disaster emergency activity. Cleaning up blown-down timber was a great challenge for the many public and private agencies that cooperated to tackle the job. The Station's main contribution was to prepare slash-disposal standards based on silvicultural considerations. These standards were used in the cleanup of the hurricane zone. The Station also studied the economic impact of the hurricane on the local communities.

Salvage of timber blown down by the hurricane disclosed three facts about New England: the low quality of its second-growth timber; the low level of its forest-product manufacturing operations; and its marketing problems. As a result, the hurricane stimulated the interest of the Station and other agencies in planning a regionwide forest policy plus a program of state regulation.

The hurricane was a blow to the Station's own research program. Almost 70 percent of the 663 sample plots on the Gale River and Bartlett Experimental Forests were damaged. Many had to be abandoned. Years of study were lost, and months of inventory and cleanup were necessary.



A Change at The Allegheny Station

Forbes left the Allegheny Station in 1939 to go into private business in forestry consulting, teaching, writing, and editing. He had organized the Station, recruited a staff, formed an Advisory Council, acquired research facilities, and initiated a research program.

Hardy L. Shirley succeeded Forbes as director of the Allegheny Station. Shirley, a graduate of the State University of New York College of Forestry, with other degrees from Indiana University, Yale University, and the University of Helsinki, had taught for several years before joining the U.S. Forest Service as a silviculturist.

Hardy L. Shirley.



Hurricane damage on the Gale River Experimental Forest. September 1938.

THE WAR YEARS 1941 TO 1945

Northeastern Station at New Haven Closed

World War II hit the experiment stations of the Northeast very hard—after they had already been struggling through the Depression with inadequate financing. The Forest Service—trimming its sails to the winds of war—decided to close down the Northeastern Station at New Haven.

On 30 June 1942, Director Behre announced that the Station was closed “for the duration or longer”. The research scientists, some of the clerical staff, files, property, and the three most important research projects were transferred to the Allegheny Station in Philadelphia.³ Behre went to Washington to take up new duties for the Forest Service.

The New Northeastern Station

The new combined unit at Philadelphia was renamed the Northeastern Forest Experiment Station. It was to be responsible for federal forestry research in the New England and Middle Atlantic States. Thus began the present Northeastern Station.

About this time the Station moved its headquarters from the University of Pennsylvania campus to larger quarters in central Philadelphia.

Director Shirley was confronted at once with a diplomatic problem: many of the supporters of the old Northeastern Station, including some of the Advisory Council, were disgruntled at the closing of the New Haven office. Shirley and Westveld toured New England, seeking continued support, and they received a generous response. The Advisory Council was reconstituted to include representation from the entire region; and this Council has operated effectively ever since.

These were trying times. All but the major projects were placed on a mere maintenance basis. Many men from the Station joined the armed forces, including George Fahnestock, Robert Gregory, and John McGuire. G. R. Trimble went to the upper Amazon to work on production of cinchona bark, source of quinine.

The Station went onto a 6-day 48-hour work week. Gasoline rationing added to the strain. But the work went on.

Wartime Research

Timber for war use became a major concern. A small program had already been begun in cooperation with the Forest Products Laboratory to expedite logging, lumber manufacture, and secondary timber processing. Fred C. Simmons was appointed to work on logging and milling, and Roy M. Carter on secondary processing. Their work helped many new loggers and sawmill men who, stimulated by high wartime prices, went into the lumber business.

Silas Little—one of the first foresters to anticipate the use of fire as a silvicultural tool, not only to minimize damage from wild fires, but also to control species composition—carried out research on prescribed burning in New Jersey, in cooperation with state foresters. This work was impelled partly by the need to control fires around military bases in the New Jersey Pine Barrens. Some of the old-line fire-fighters objected to this use of fire, but subsequent research confirmed the effectiveness of controlled burning as a silvicultural tool.

A survey was made of the forest resources of the Anthracite Region of Pennsylvania, which were found sadly depleted. Soils were thin, impoverished by fires and erosion. This survey laid the groundwork for later forest-survey work. Miles Ferree, Earl Rogers, and Roland Ferguson developed the use of aerial photos for survey work and contributed toward techniques that aided in developing the present forest-survey system.

The Station also studied the problems of rehabilitating coal-mine spoil banks in the Anthracite Region, anticipating the present growing concern for the environment. William E. McQuilkin of the Station staff worked on this project. J. R. Schramm of the University of Pennsylvania Botany Department encouraged this work and supported it. The problems involved much more than rock and coal wastes: acid in water from mines and mine spoils,

black soils that reached temperatures lethal to plants, and absence of soil flora and fauna to help break down the minerals to create conditions favorable for tree growth.

The Station owed much at this time to Clement Mesavage and his brother Stanley, who had a passion to better the environment and economic welfare of people in the Anthracite Region. Their efforts helped gain Congressional support for the Station's work in the war years.

One highlight of the war years was the work of Ash Hough, who studied reproduction of hardwoods on the Allegheny Plateau. He found that good reproduction of valuable species like black cherry came in after the first clearcutting of old-growth timber, but that repeated cutting of second- and third-growth pole stands for chemical wood led to rapid deterioration of the forest stand. Hough also contributed to the understanding of old-growth natural stands.

The Beltsville Experimental Forest in Maryland was built up during the war. Little money was available, but with the help of conscientious objectors assigned to wartime work with the Forest Service, the facilities were improved and research work was pushed ahead. Studies were made of waxy sprays to increase survival and growth of tree seedlings by reducing transpiration, and dressings to speed the healing of tree wounds were tested.

The Station continued to support the Otsego Cooperative. The Cooperative was helped by high wartime lumber prices, and despite financial and managerial problems, looked promising. But after the Station discontinued its Cooperstown unit in 1948, the Cooperative began a slow decline and eventually failed. Later studies showed that the Cooperative's greatest success was its sawmill operation—not its forest-management program.

The staff also contributed to miscellaneous war-time studies such as methods and materials for camouflage.



A Civilian Conservation Corps crew cutting stump sections for study after logging of virgin hardwood forest near Ludlow, Pennsylvania. August 1936. During the depression years, the CCC provided manpower for Forest Service research.

A CCC crew plants red pines for a seed-source study at the Kane Experimental Forest in Pennsylvania. April 1937.



EXPANSION 1945 TO 1973

The war ended. The nation turned its attention back to domestic problems. An era of expansion in forestry research began.

In 1945, Hardy Shirley left the Northeastern Station to become assistant dean, and later dean, of the State University of New York College of Forestry at Syracuse. Shirley had consolidated the two old experiment stations into the new Northeastern Station, kept it going productively through the war years, and now left it "in tidy order for my successor".

Verne L. Harper was his successor. Harper received his bachelor's and master's degrees in California and his Ph.D. at Duke University. From 1927 to 1937 he served at the Southern Forest Experiment Station, mainly on naval-stores research, advancing to chief of forest

management and forest influences. From 1937 to 1943 he served as assistant chief of the Division of Silvics in the Forest Service Washington office, and from 1943 to 1945 he was chief of the Division of Forest Economics Research.

A New Era Begins

Harper foresaw "a new era in forestry research." He predicted that the growing population of the Northeast would put increasing pressures on the forest resource. A broader concept of forestry was needed. "Forestry," he said, "embraces much more than planting and growing timber and protecting it from fire."⁴

In 1946, peace-time forest needs assumed a priority they would hold despite the Korean War emergency of the early 1950s. Mid-century America was faced with sustained international tensions that prompted intensive research into the nation's long-term forest needs.

Harper put high priority on working closely with individuals and groups throughout the Northeast to bring about the new era in forestry research. These groups included the Station's Advisory Council; heads of universities; agricultural experiment stations and forestry schools; state forestry and conservation departments; river-basin councils and watershed associations; sportsmen's clubs; and state and federal legislators.

The first task, which absorbed most of Harper's time beyond his internal duties as director, was to build a widely shared awareness of the many benefits to be gained from the region's richly endowed forest land under a program of advanced management and use, and of the contributions that could be made to proper management and use through adequate forestry research. The second task was to translate awareness into public response that would lead to increased federal funding of the Station's programs.

Results were not long in coming. In 1946 flood-control surveys were resumed to cover, over a period of years, all the major river basins in the Northeast.

Verne L. Harper.



In that same year the national Forest Survey for the first time was brought to the Northeast with a commitment to the Station for the employment of a permanent survey organization to make periodic inventories for keeping up-to-date information on timber volumes, quality of wood, and associated forest conditions.

Forest economics research, closely associated with the Forest Survey, was strengthened in 1946 and subsequent years. New programs were launched in logging and timber utilization and marketing studies. Timber-management programs received a substantial increase in 1946 and subsequent years to enable the Station to launch a steady silvicultural research push in each of the region's principal forest types.

Forest-genetics research was strengthened. Watershed research, previously funded on an emergency or survey basis, got regular sustained funding, beginning in 1947, that permitted the establishment of projects in West Virginia and Pennsylvania. Wildlife-habitat studies were undertaken in 1947 in West Virginia in cooperation with the State's Department of Conservation.

By then the Station's headquarters offices in Philadelphia had become crowded with people and activity. In May 1948 the offices were moved to more spacious quarters in Upper Darby, Pennsylvania, a suburb of Philadelphia.

In 1949 a severe drought occurred in New York and northern New Jersey. That same year, two serious floods occurred, one in New York and Connecticut, the second in Virginia and West Virginia—both attributed to runoff from overgrazed, burned, logged lands that could not absorb the heavy rainfall. Flood-control surveys were extended.

Urged by the Station's Advisory Council, the Delaware River Basin Council, and other local groups concerned about water problems in the postwar 1940s, watershed-management research was broadened as a regularly funded part of Station research in New England and the Middle Atlantic States. Research programs begun in 1946 and continued in the 1950s and 1960s helped to bring improved knowledge of forest-watershed management,

more secure municipal water supplies, and greater soil stabilization in the region.

Equally significant to research progress, the Station began programs of research-facility-improvement and personnel development. Enlarged headquarters of the Station were equipped with the latest models of data-processing equipment, and new aerial-photograph techniques were pioneered. Laboratory and office space was renovated or newly constructed at the Station's field centers.

A personnel-development program was begun that stressed advanced training and assignments calculated to enhance scientific skills and research performance. Many of the Station's scientists recruited during the post-war 1940s later went on to higher positions elsewhere.

For example, Thomas F. McLintock, recruited in 1946, directed the Station's timber-management research in the spruce-fir type, then went back to school to acquire his Ph.D. After several assignments at other stations, he was called to Washington as director of the Forest Service's Division of Environmental Research.

Herbert C. Storey, who came to the Station in 1948 to establish the new watershed-research project in Pennsylvania, became chief of watershed-management research at the Station, and then went to Washington as director of Forest Service watershed research for all stations and, later became associate deputy chief for research.

And John R. McGuire, recruited in 1946 to establish the Station's white pine management program, took advanced training in economics, became head of the Station's economic research, became director of another station, and in 1972 was appointed Chief of the Forest Service.

Continued Progress

In 1951, Harper left the Northeastern Station to go to Washington as Forest Service Deputy Chief of Research, later becoming Chief of Research. He had directed the Station through its period of greatest growth, from the smallest station in 1945 to one of the largest in 1950. At the Station, and later at the Washington office, he laid the foundations for future

Ralph W. Marquis.



research by all the Forest Service experiment stations.

Ralph W. Marquis succeeded Harper as director in 1951. Marquis, a graduate of the University of Washington, with M.A. and Ph.D. degrees from the University of Wisconsin, was an associate professor of economics at Rochester University before joining the U.S. Forest Service in 1940 as a forest economist on the Washington office staff.

The "new era in forestry research" that Harper had predicted came to pass. America's transition from a nation with a surplus of raw materials to an importer of raw materials forced recognition of the need for resource conservation. Domestic consumption of wood products soared. Forest land values increased dramatically. Profits rose in the forest industries. More effective and efficient methods of timber production, utilization, protection, and regeneration became imperative.

Pressures on the forest resource increased steadily. Forest uses other than timber production came into prominence, causing conflicts.

Urban centers grew. Forests became even more essential for municipal water supplies, flood control, recreation, and wildlife habitat. In some places these uses became more important than timber production.

Since its inception, the Forest Service had assumed responsibility for research into all forest uses. During the 1950s and 1960s, responding to consumer and environmental needs, the Forest Service articulated its multiple-use policies. In 1960 Congress passed the Multiple Use-Sustained Yield Act, defining multiple use as management of "all the various surface resources" of the forests so they are "utilized in the combination that will best meet the needs of the American people."

Following this policy, the Northeastern Station expanded its activities to coordinate development of research on all forest uses. Timber management and associated protection and utilization, emphasized at the start of Forest Service research in the Northeast, remained prominent in the program. But watershed management and forest economics, explored in the 1930s and tackled in earnest in the post-war 1940s, assumed equal importance. And in 1959 wildlife-habitat and recreation research became regular parts of the Station program. Environmental considerations caught increasing attention from Station scientists in the 1960s.

In both the older and newer research fields, new techniques and approaches were tried. Chemicals were discovered that proved valuable to the forester for disease, insect, and fire control as well as stand improvement. Biological controls and radiation were tried for the first time in the forest. Use of aircraft revolutionized inventory surveys, fire suppression, and disease and insect control.

Use of high-speed electronic computers made it possible to store great amounts of data and to sort them and retrieve information quickly and easily. New mathematical models were applied in all fields from timber management to recreation. Researchers probed problems with behavioral models, simulation procedures, and systems analysis.

As research needs and capability increased, so did Station facilities. Funding increases in the 1950s allowed laboratory construction and

larger staff. Despite some budgetary limitations in the 1960s, Station programs continued to grow. Old projects were completed and new ones begun, many of a kind not visualized in earlier years.

Administrative Changes

To cope with the increasingly complex research programs and problems, the organizational structure of the Station was modified.

When, in the late 1940s, the Station organized research centers, these were seen mainly as locations for timber- and watershed-management research—though a few special centers were devoted to other projects such as genetics. Most of the other research activities were centered at the Station's headquarters.

The research centers were like miniature experiment stations, each with its leader who was responsible for all projects. As the 1950s passed, it became obvious that this arrangement had its disadvantages. The research center leader was overburdened with administrative chores, and the setup clamped a low ceiling on grade advancement of project scientists.

It became obvious that further decentralization was desirable for expanding programs in forest product marketing, forest engineering, and wildlife habitat—especially as the nationwide program of laboratory construction got under way.

In the servicewide reorganization of research in 1959, a new structure was adopted. By 1960 the Northeastern Station—like all the other stations—had decentralized so that the basic unit became the project.

Each project leader was responsible for his research work unit. He looked to an assistant director at headquarters for direction and coordination. Meanwhile, administrative people were assigned to the field units to relieve the scientists of most administrative chores. This was in line with the national policy to de-emphasize administrative layers and to emphasize the training and advancement of project scientists.

The number and locations of the field units varied in the 1950s and 1960s in response to changing needs and appropriations. In 1958 there were 11 centers. This number increased until 1965 and 1966 when budgetary cutbacks

placed a ceiling on the number of employees. Then the Station began to consolidate field locations. There are now 14 project locations—all different from those of 1958.

In a Department of Agriculture reorganization in the early 1950s, forest insect and disease research was transferred from the Agricultural Research Service to the Forest Service. The Northeastern Station assumed direct responsibility for such research in its region. The Station's insect and disease research is now carried on at modern laboratories at Hamden, Connecticut; Delaware, Ohio; and Durham, New Hampshire.

In 1966, Ralph Marquis left the Station, called to the Washington office to serve as assistant to the Deputy Chief for Programs and Legislation. Marquis had steered the Station through changing times and continued expansion. He was concerned with expansion to encompass the many new facets of research required by the multiple-use concept, laboratory construction, and the shift from the research-center-leader concept to the project-leader organization. Marquis died the day after he retired from the Forest Service, 14 December 1966.

Richard D. Lane succeeded Ralph Marquis as director. Lane took his bachelor's and master's degrees at Iowa State College and joined the Forest Service at the Central States Forest Experiment Station, served a while in National Forest Administration, then returned to the Central States Station, where he headed the Carbondale research center in 1947-56. He served at the Northeastern Station in 1956-59 as chief of the Division of Timber Management, then on the staff of the Timber Management Research Division in Washington for 1 year and back to the Central States Station, where he was director in 1960-66.

Lane came back to the Northeastern Station as director early in 1966, when the Forest Service reorganized its eastern experiment stations. In this reorganization the Central States Station, headquartered at Columbus, Ohio, was closed; and its personnel and projects were divided between the Northeastern Station and the North Central Station. The Northeastern Station took on added responsi-

Richard D. Lane.



bility for federal forestry research in Ohio and Kentucky, which increased its area of responsibility to 14 states.

At this time, the Northeastern Station's headquarters were moved to their present location at 6816 Market Street in Upper Darby, to occupy the same building as the State and Private Forestry Northeast Area office.

With this reorganization, the Northeast became the only place where the Forest Service has headquartered a regional State and Private Forestry director's office with an experiment station, separate from national forest administration. This emphasized that a major task of State and Private Forestry is to promote the adoption or implementation of research findings by the states and private industry.

This realignment strengthened cooperative forestry programs on state and private lands and provided a closer link between these programs and the research of the Forest Service in the East.⁵

Director Lane left the Station in 1970. During his time as director, he worked to coordinate the activities of the Station with the State

and Private Forestry organization. The development of cooperative relations was important among his activities. To promote the nationwide policy for cooperation with State and Private Forestry to get research results into use, he established an information service in the Station, to disseminate research findings through the mass media of radio, television, and the press. In 1970 Lane transferred to the Agricultural Research Service and took an international assignment in forestry in New Delhi, India.

In 1970, Warren T. Doolittle succeeded Lane as director. A silviculturist and soil scientist by training, Doolittle took his bachelor's degree at Iowa State University, a master's degree at Duke University, and a Ph.D. at Yale. He served as a research forester at the Southeastern Forest Experiment Station in 1946-57, at the Washington office in 1957-59, and came to the Northeastern Station in 1959 as assistant director for research in timber management, watershed management, engineering, recreation, and wildlife habitat. In his 2 years as director he has worked to strengthen the research effort in general. In particular Doolittle has promoted the development of environmental forestry research.

Warren T. Doolittle.



SOME HIGHLIGHTS OF RESEARCH ACTIVITIES AND ACCOMPLISHMENTS

Timber Management

The Northeastern Station's timber-management program has revolved around the silviculture of the five dominant forest types of the Northeastern Region.

The spruce-fir forests occur in northern Maine, northern New Hampshire, the Adirondacks of New York, and to a minor extent in the mountains of West Virginia. Research on this forest type is centered at Orono, Maine, where Station researchers are studying problems of reproduction, cutting methods, growth, soil nutrition, and protection against animal damage. Acceleration of spruce regeneration has been a major consideration, crucial to the pulp and paper industry, one of the leading forest industries of the region.

Northern hardwoods—beech, yellow birch, and sugar maple—are found predominantly in New England, New York, and Pennsylvania. Although these hardwood forests regenerate naturally, maintenance of stand quality is difficult. After cutting and burning, some areas may be taken over by aggressive and less desirable species such as aspen, pin cherry, or gray birch.

Research on stand quality has been under way for many years on the Bartlett Experimental Forest and is now conducted from the laboratory at Durham, New Hampshire. Researchers concluded long ago that artificial regeneration, through planting or seeding, is uncertain and expensive.⁶ Early elimination of competitors is preferable for favoring the desirable species that seed in naturally. Station researchers found methods of killing the fast-growing weed species, including the use of herbicides, tree girdling, and weeding. The Station also maintains a project, now centered in Burlington, Vermont, for studying methods of increasing sugar maple sap production.

The white pine-hardwood forest type is found roughly in the middle of the Northeastern Region—southern Maine, New Hampshire, Massachusetts, Connecticut, New York, and Pennsylvania. White pine is a desirable commercial species that does not always reproduce well naturally.

In 1955 the Station broadened its white pine project, begun in the 1940s, into a comprehensive program embracing many facets of forest production. One problem was to establish white pine reproduction free of hardwood and brush competition.⁷ By 1969 part of this problem was solved with a direct-seeding method that proved practical: the seeds were planted in furrows with a tractor-drawn machine.

The oak-yellow-poplar forest type is found in southern Connecticut, parts of New York, most of New Jersey except the Pine Barrens, southern Pennsylvania, central and western Maryland, and nearly all of West Virginia. The composition of this forest type varies greatly according to elevation, latitude, and soil. Research on this forest type, though focusing on regeneration, has ranged from a search for methods of protecting planted acorns of the coastal oaks to studies of stocking for the upland hardwoods—oak, yellow-poplar, maple and hickory—in Ohio.

In 1971, after 20 years of study, the Station was able to make confident recommendations for the management and silviculture of these upland oak stands.⁸

The need to improve conditions of the long-abused forests of the Coastal Plain was urgent because of their proximity to large population centers. The research center at New Lisbon, New Jersey, had success in regenerating yellow-poplars of the Coastal Plains and Piedmont.

The yellow pine-hardwood forest type—a relatively minor one—is found along the coastal areas of Massachusetts, New York, New Jersey, and Maryland. The yellow pines include pitch, loblolly, shortleaf, Virginia, and pond pines. The most common associated hardwoods are oaks, hickories, red maple, white-cedar, blackgum, sweetbay, sweet gum, and holly.

Pines are the preferred species on most sites, but Atlantic white-cedar is preferred in the swamps. Silas Little, at the research unit at New Lisbon, New Jersey, did outstanding research on the ecology, silviculture, and man-

agement of white-cedar and its associated species.

Studies of the pine-hardwood forest type in New Jersey before 1950 dealt with methods of obtaining natural reproduction through using fire or machinery for seedbed preparation, and prescribed burning for reducing fuels on the forest floor to protect the forest from wildfires. After 1950 similar studies were made in eastern Maryland, as well as allied studies in both states on types and techniques of herbicide treatments for controlling undesirable hardwoods in different forest conditions, effects from different kinds of thinnings, growth of pines from different geographic sources, methods of direct seeding, and effects of planting methods on stem growth and root systems.

Silvicultural Systems and Cutting Methods

During the past 50 years, the Station has tested many methods of intermediate and harvest cutting in different forest types, in a search for the kinds of silviculture that will keep the land producing high-quality timber of the most desirable species. Studies covered both uneven-aged management with many intensities of selection cutting, and even-aged management with various forms of regeneration cutting, including clearcutting.

The concept of selection cutting was brought to this country by foresters trained in Europe early in the century. In this kind of silviculture, periodic inventories are used to keep track of stand growth, and individual trees or small groups of trees are selected for harvesting at relatively short intervals to conform to the stand growth rate. The objectives are to remove products at only the rate at which they are grown (or at a somewhat lesser rate if it is necessary to build up growing stock) and to keep on the land a continuous, well-stocked forest cover in which all age classes of trees, from saplings to maturing sawtimber, are heterogeneously intermingled.

In even-aged management, age classes are kept separate. The forest is regulated to contain all age classes of trees distributed among many stands, but in any one stand the trees are all the same age. Each stand is treated as a unit while the trees within it grow from sap-

lings to sawtimber. At maturity the stand is regenerated as a unit by one of the types of regeneration cutting, all of which have one thing in common: for a short period after the final cut, the stand is devoid of any large tree cover, though seedlings and small saplings may be numerous. In even-aged management, sustained yield is ensured by controlling the amount of area in each age class and by proper timing of the regeneration cutting.

As time passed, evidence from Station studies (some begun as early as the 1930s) showed that single-tree selection cutting would successfully regenerate sugar maple and beech, but failed as a regeneration method for many desirable species such as yellow-poplar, paper birch, and black cherry, which require plenty of light to survive and grow. Selection cutting by groups will satisfactorily regenerate these and other species, but under group-selection cutting, unless the groups are very large, regulating the rate of cutting for sustained yield on large forests is difficult and costly.

Research by the Station also showed that several forms of even-aged regeneration cutting are highly successful in regenerating most species of hardwoods when proper conditions exist.⁹ Shelterwood cutting and clearcutting—either in blocks or in narrow strips or small patches—can be used successfully to regenerate almost all our northeastern hardwood species. But the proper conditions necessary for success vary for different species and may vary in different parts of the species' range.

In some areas recreation and esthetic values may preclude even-aged management entirely. In such cases single-tree selection cutting or group-selection cutting will perpetuate the forest, though with possible loss of efficiency in timber production and less benefit to some species of wildlife.

In the 1950s and 1960s, as demand for lumber grew, logging costs became more of a problem than before. The Station responded with attention to the financial problems of the logging industry, making cost-and-return studies through the use of simulation techniques applied to stands on the experimental forests. Applied on areas of commercial size, these new techniques simulated industrial operations.

The impact of cutting method on watersheds and wildlife was also taken into account. At the Farnow Experimental Forest on the Monongahela National Forest in West Virginia, Station scientists studying the impact of clearcutting on streams found that well-planned cutting of hardwood forests did not cause flooding or severe erosion. Erosion reflected the care taken in logging rather than the cutting practice. When properly applied, clearcutting tended to bring about a more dependable streamflow.¹⁰

The impact of clearcutting on wildlife has been another facet of the Station's growing research focus on the interrelation between forest cover and wildlife habitat. Studies were made to determine the impact of timber harvesting on forest animals. Means were explored of reducing the destructive effects of browsing animals, such as deer, on forest regeneration.¹¹

Forest Genetics

Station research in forest genetics—a basic component in timber-management, entomology, pathology, and environmental research—was begun in 1936 at New Haven. Leader of the project, from then until he retired in 1972, was Ernst J. Schreiner.

Schreiner had previously worked in the pioneering Oxford Paper Company project of the 1920s to create hybrids that would produce wood fiber fast. After joining the Station he won international fame for his work in forest genetics, especially for developing fast-growing hybrid poplars.

In 1942, the project was centered at the University of Pennsylvania's Morris Arboretum in Philadelphia, though Schreiner, still project leader, served in 1945-50 as leader of the work center at Beltsville, Maryland. In 1963 the project was moved from the Morris Arboretum to the research unit at Durham, New Hampshire.

The project's objectives, briefly summarized in 1937, are: "The development of superior forest tree types adaptable to a wide range of environmental conditions and capable of producing a diversity of high-quality products in the shortest possible time, and analogous improvement of the inherent quality of natural

forest stands by the application of knowledge derived from genetical research."

This project included the need for developing genetically improved trees particularly suited for both intensive and extensive forestry, for flood control and soil conservation, for wildlife conservation, and for amenity uses.

Hybrid poplars.—Cuttings of selected hybrid poplars have been distributed worldwide. Some of these hybrids have come into commercial use in several European countries, and additional hybrids are included in commercial trials in other foreign countries.

Cuttings of 60 selected hybrid poplars were distributed in the United States for cooperative clonal tests between 1938 and 1941. Results were doubtful because few of the cooperators followed instructions for site preparation and first-year cultivation. In 1955, cuttings of 70 promising hybrids were distributed to approximately 3,500 individuals throughout the country in a nationwide cooperative test. Some of these have shown outstanding possibilities in many parts of the country, with particular promise for revegetation of strip-mine banks in Pennsylvania.

Forty hybrids, selected on the basis of their growth in 15-year tests at the Hopkins Experimental Forest in Massachusetts, were released in 1970 and 1971 through State and Private Forestry for commercial trials in the Northeast. They were rated on growth rate and disease risk for use in plantations for mini-rotation fiber, boltwood, or timber production.

Breeding with other species.—Selfing, intra-specific breeding, and interspecific hybridization with six important genera (maple, birch, ash, spruce, pine, oak) to determine self-compatibility, species crossability, and characteristics of species hybrids, have been a major part of the genetics work since 1937. As a result of this extensive breeding work, more than 30,000 seedlings have been outplanted in plantations scattered throughout the region.

Provenance tests.—The project has three provenance studies under way (with *Fraxinus americana*, *F. pennsylvanica*, and *Pinus strobus*) and two cooperative studies with *Picea abies* (IUFRO) and *Pinus echinata* (Southern Forest Experiment Station).

Search for superior genotypes.—The search for genetically superior individuals of our na-

tive species is a continuing job. Potentially high sugar-producing sugar maples are under test by geneticists at the Burlington, Vermont, laboratory. Promising white pines are being tested for weevil resistance at Durham, New Hampshire. Several techniques have been used in the white-pine weevil resistance work: the determination of density of resin ducts at the feeding sites, rate of resin crystallization, and—most recently—the investigation of chemicals such as terpenes and resin acids in attacked and unattacked trees.

All these approaches have indicated the complexity of this research. In addition to the search for resistance in eastern white pine, exotic species and species hybrids are being tested.

Watershed Management

After World War II, interest in and support for watershed management increased. The Station's main research efforts in this field have been on the Delaware-Lehigh Experimental Forest in Pennsylvania (established in 1948 by the Pennsylvania Department of Forests and Waters), the Fernow Experimental Forest in West Virginia (starting in 1949), the Hubbard Brook Experimental Forest in New Hampshire (established in 1955), and recently on the Newark, New Jersey, and Baltimore, Maryland, municipal watersheds.

Fundamental relationships of the forest and forest practices to flood runoff, water yield, erosion, and sedimentation have been determined and widely published. Possibilities for increasing water yield by cutting trees have been demonstrated. Also, it was shown that the construction and use of roads and trails rather than the cutting of trees were the causes of erosion during timber harvest; practicable methods for controlling erosion during and after logging were developed and demonstrated to landowners and operators.

This knowledge has proved invaluable as an input to multiple-use forest management. Howard W. Lull, who headed this work from the early 1950s to the late 1960s, earned an international reputation as a forest hydrologist.

Of special interest in this age of the environment, recent work at Hubbard Brook—and

also on the Fernow Forest—has provided a start in determining the relationships of forest-management practices to the discharge of nutrients in streamflow and to the nutrient cycle in the ecosystem. The Station's research in forest hydrology and other aspects of watershed management has provided a much needed base for current work on municipal watersheds and on forest influences in the urban-suburban environment.

Surface Mine Reclamation

Since World War II, strip-mining for coal has increased tremendously. Strip-mining can have a devastating impact on the environment—especially on the visual appeal of the landscapes, on streamwater quality, and on land productivity.

The Station has an active effort in surface-mine reclamation. It started as a modest timber-management program at Kingston, Pennsylvania, in the late 1950s. When the Central States Experiment Station was phased out in 1965, this research effort was consolidated with a larger project at Berea, Kentucky.

Carried on as a watershed-management project, this effort is actually a multi-functional research unit with responsibility for all Forest Service surface-mine reclamation research in the eastern United States: In cooperation with the states and industry, it has concentrated on the revegetation of mined areas, but work on hydrology and engineering has been included.

Results of this work have been incorporated into regulations of the state agencies and have been put into practice by industry in all the Appalachian coal-mining states.

Utilization and Marketing

The Northeastern Station first edged into utilization activities during the timber salvage cleanup after the New England hurricane of 1938. During World War II, the Station got into utilization for good. Getting out timber for wartime use became a major Forest Service task.

After the war, a Forest Utilization Service was established to bring utilization problems to the attention of the Forest Products Lab-



Prescribed burning in New Jersey. A 100-foot safety strip is being burned along the boundary of the Lebanon Experimental Forest to reduce fuel on the forest floor. March 1937.



Screen tests at Bartlett, New Hampshire, for determining the light requirements of northern hardwoods for regenerating strip cuttings.



The weir on a gaged watershed on the Fernow Experimental Forest in West Virginia. A continuous record of watershed behavior will show how forestry measures and logging affect the water resource. An automatic recorder in the gage house charts the behavior of the stream.

oratory for research, and to help get Laboratory findings put into practice. James C. Retie headed this project, later succeeded by Charles R. Lockard.

At this time, a revolutionary change was taking place in logging, milling, and utilization. Before the war, most logging had been done with hand tools and horses. Now the gasoline chainsaw came onto the scene. Other new machines and methods were being developed fast—skidders, loaders, automated sawmills, short-log bolter and sash-gang saws, and new lumber-drying and handling methods.

The Station's Forest Utilization Service was in the forefront of this revolution. Though much of the work was by nature more extension than research, considerable research was done that resulted in significant findings.

Fred C. Simmons wrote hundreds of articles and papers to help loggers and mill owners make the transition from the old ways to the new. His USDA bulletin on *Logging Farm Forest Crops in the Northeast* (1949) became a bible for the farmer who had woodlot timber to harvest. His *Northeastern Loggers' Handbook* (1951) was one of the Station's all-time best sellers. Translated into foreign languages, it was used widely abroad, especially in underdeveloped countries. After his retirement from the Station and a United Nations mission in South America, Simmons became editor of the trade journal, NORTHERN LOGGER, and Executive Secretary of the Northeastern Loggers Association.

Meanwhile, Lockard had much to do with the development of the log and lumber quality studies that gave sawmill operators a means of determining timber quality and value. These studies, continued by Myron D. Ostrander and Roswell D. Carpenter culminated in the publication of sawlog grades for both hardwoods and eastern white pine.

In 1961 the Station expanded its program of research on timber marketing and utilization. Most of this research was concentrated at a new Station facility, the Forest Products Marketing Laboratory at Princeton, West Virginia. In addition to the main laboratory building, a methods-testing plant was built. The scientists at this laboratory tackled the utilization and marketing problems of wood-

based industries of the Appalachian hardwood region.

Appalachian sawmill operators faced rising stumpage and harvesting costs and diminishing supplies of high-quality sawtimber in the 1960s. To help solve this problem, Station scientists sought ways to improve the utilization of high-grade timber. At the same time, they sought expanded uses for low-grade timber.

For example, they developed a computer program called SOLVE, which shows how much sawmill operators can afford to pay for logs, and how they can allocate costs among their production processes. Many operators now use this program for evaluating their operations.

Marketing research has also demonstrated the economic feasibility of low-temperature lumber drying with the accelerated kiln-drying methods developed by the Forest Products Laboratory for hardwood lumber. These drying methods permit a substantial reduction in the lumber inventory a mill must have to assure users of an adequate supply of dry lumber.

Forest-products technologists at the Princeton Laboratory developed a new mill process through which low-grade tree-length logs can be economically converted into high-quality pallet parts and pulp chips. Marketing analysts determined that new highly automated sawmills with relatively small-scale operations (10 to 15 thousand board feet per day) are more efficient and profitable than larger band and circular mills in the production of lumber from low-grade logs.

Market researchers developed and patented a quick leveling method for rehabilitating floors in urban rehabilitation projects. In this system a quick leveling device holds 2 X 2-inch wooden screeds in a level position over old sagging floors while a quick-hardening urethane foam is sprayed underneath to fill the gaps and bond the screeds to the old floor. The screeds provide a good base for a new level floor.

A study on the use of wooden pallets, done in cooperation with the National Wooden Pallet and Container Association and Better Management Services, showed that unit-load handling with wooden pallets can provide sub-

stantial benefits to the transport industry. For example, the cost of handling a case of food products can be reduced from 25 cents to 6 cents by handling pallet loads rather than individual cases. Expanded use of pallets by the food industry alone could provide a profitable outlet for much of the low-grade timber available in the United States today. Research demonstrated that a pallet-exchange program among the food-industry firms would further reduce costs of food shipment.

Other marketing and utilization innovations that have been evaluated and found potentially profitable include the production of structural grade plywood from low-grade hardwood timber and the use of small mobile post-driving machines that make it feasible for wooden posts to be used as effectively as steel posts in highway guardrail systems.

Insects and Diseases

When the experiment stations were established in the Northeast in the 1920s, one of their major missions was to find ways to protect forests from fire, insects, and diseases. At the beginning, insect and disease research was done by scientists assigned to the Station by the Bureau of Entomology and the Bureau of Plant Industry. These people worked as part of the Station staff.

In 1954, the Department of Agriculture transferred forest insect and disease research to the Forest Service. Raymond C. Brown and John R. Hansbrough were appointed Station division chiefs for insect and disease research. Since then this research has been a regularly funded part of the Station program.

When the present Northeastern Station headquarters were set up in Philadelphia, the old Station headquarters on Prospect Street in New Haven became the center for insect and disease research. After this building burnt down in 1964, the staff occupied temporary quarters in West Haven till the new laboratory at Hamden was completed. Insect and disease research is now being done at laboratories at Hamden, Connecticut; Delaware, Ohio; and Durham, New Hampshire.

One of the most persistent pests the Station has dealt with is the spruce budworm. In the 1940s a budworm epidemic swept through the

spruce-fir forests of Canada into Maine, defoliating and killing timber on vast areas. Silvicultural methods were tried, by identifying high-hazard areas and cutting them first.

DDT was found to be effective against the budworm, and methods of airplane spraying were developed that eventually helped to bring the epidemic under control. Research continued into the 1960s, to refine control methods. The chemical Zectran was found to be an effective alternative to DDT.

The gypsy moth defoliates both conifer and hardwood trees, especially oaks. Introduced from Europe in the 19th century, this pest multiplied beyond control and severely damaged forests in southern New England. For some years it seemed fairly quiescent; then the populations swelled; but now it is spreading west and south, threatening great damage.

In the 1950s, DDT was used to combat outbreaks. In the 1960s, chemicals with less persistent toxicity than DDT were tried. In the search for a control method, Station researchers tried sterilizing males with gamma radiation; they tried predators, parasites, and virus and bacterial diseases of the moth. A computer model was developed for predicting the course of a gypsy moth epidemic.

Despite all these efforts, the gypsy moth continues to plague the region; and in 1971 an intensive 5-year program was begun in a search for a way to control this pest. A special program was set up at the Hamden Laboratory to carry on this work.

Many other pests have been studied in efforts to control them or lessen the damage, including the white-pine weevil, balsam woolly aphid, southern pine beetle, European sawfly, and various scale insects.

Also doing great damage is the Dutch elm disease, which is estimated to have killed 400,000 elm trees annually through the 1960s. The carrier of the fungus that causes the disease has been identified as a beetle. Spraying with chemicals was found to have only a stalling effect on the beetles. Wasp parasites imported from France were first released in 1967, and populations have become established in some areas. It is still too early to determine their impact on beetle populations.

A possible weapon against the beetle was found in 1970. Researchers at our laboratory

at Delaware, Ohio, discovered that the female beetle secretes a chemical sex pheromone that attracts the male; and they speculated that this might be used to lure and kill the males or disorient them to prevent mating. And in 1972, a method and equipment were developed for injecting trees with a fungicide, benomyl, for both preventing and arresting the disease. This seems like a real breakthrough; however, it is still under test.

In forest pathology, Station scientists have tackled a number of forest tree diseases. Perley Spaulding, one of the first plant pathologists in the United States, studied white pine blister rust and devised a control method in which the alternate hosts of the fungus pathogen, *Ribes* (currants and gooseberries), were eradicated to keep the disease from the pines.

One of the early forest-pathology problems investigated by Station scientists was the chestnut blight, which all but wiped out the American chestnut, once one of the most plentiful and commercially valuable of the eastern hardwoods. No control was found for this disease; yet for years the Forest Service continued efforts to bring back the chestnut by selecting and breeding resistant varieties.

Jesse D. Diller, leader of this project for the Station, scoured the East looking for survivors that might have genetic resistance to the disease. Some were found, some that survived long enough to bear fruit; but none proved completely resistant.

Resistant chestnut species were imported from China, Japan, and other countries and tested in various parts of the United States. Some of these survived our climate and were resistant, but none had the true forest tree form of our native chestnut. Crosses were made between the resistant Asian varieties and our American tree. One of these, the "Clapper" chestnut, shows promise, but further tests are needed to verify its resistance and produce clonal material for outplanting.

Oak wilt, which threatened the oak forests of the region, was also studied. It was found that one way the pathogen was transmitted was through root grafts; and sanitation methods—cutting to isolate diseased trees—proved to be of only limited effectiveness in tests in Pennsylvania and West Virginia.

Dieback and decline diseases of several species have been studied. Some of these were attributed to environmental stresses such as unfavorable temperature or soil moisture. Other diseases studied included white pine basal canker, nectria canker, the beech bark disease, and root rots such as those caused by *Fomes annosus* and *Armillaria mellea*.

Studies at our laboratory at Delaware, Ohio, showed that stunted growth in Christmas tree plantations, and a yellowing of tree needles—called the chlorotic dwarf disease—was caused by air pollution. Sick trees, protected from the pollution, recovered; healthy trees became sick after exposure to polluted air. The studies suggested that some trees may have genetic resistance to air pollution.

A radical new concept of discoloration and decay in trees was developed by using a chainsaw to dissect thousands of trees to study what happens inside the living tree after it has been wounded. The results upset conventional theory. After a tree has been wounded—say by a branch breaking off—a complex sequence of events occurs. First the tree has a protective chemical reaction to the wound; then organisms may invade it. Then come bacteria and non-decay fungi, which may—but do not always—pave the way for fungi that cause decay—a succession of microorganisms. The tree, however, reacts by sealing off the infected area so that the column of discolored or decayed wood is no larger than the tree was at the time of wounding: new growth put on later is clear and uninfected.

In new studies at Delaware it has been discovered that certain diseases such as elm phloem necrosis, walnut bunch, and black locust witch's broom are probably caused by mycoplasmas and not by viruses as previously thought. Although known for many years to cause disease in animals, organisms of this group were first found in plants just a few years ago. They are the smallest living organisms, only slightly larger than viruses, and are found in the phloem tissues of diseased trees.

Forest Economics

The economics of forestry became important in the programs of the forest experiment stations of the Northeast at the beginning. We

have already mentioned the old Northeastern Station's concern for small woodlot owners and its sponsorship of the Otsego Forest Products Cooperative and the Allegheny Station's studies of the depressed Anthracite Region of Pennsylvania in relation to the forest resource.

Upon consolidation of the two older experiment stations into the present Northeastern Station in 1945, a Division of Forest Economics Research was established, headed by Frank A. Ineson. Director Harper broadened the economic research program, and subsequent directors broadened it further.

The Station's small staff of forest economists have investigated many aspects of forestry economics, including taxation of forest land, forest-yield taxes, and forest insurance. A number of studies have been devoted to identifying and evaluating various opportunities for profitable investment in growing timber.

Station economists have provided guidelines for the establishment and expansion of forest-based industries. They have developed budgeting systems for allocating funds to forestry programs at state and local levels. They have established more efficient systems for grading, harvesting, processing, and marketing forest products, from woodlot to consumer.

Economic analyses have been applied to many other Station research programs. Station economists have provided economic decision-making criteria for programs of insect and disease control, watershed management, genetics, and other activities.

The Forest Survey

As part of the nationwide forest survey conducted by the Forest Service, the Northeastern Station has conducted a continuing series of forest surveys of the Northeastern States to provide up-to-date information about the timber resource and analyses of trends in forest-land area, timber volume, annual growth, and timber removals as a data base not only for state and industrial forestry interests, but also as an aid to national and regional policy decisions.

The first forest survey of the Northeast was begun in 1946. State by state, this survey covered the Northeast—some 82 million acres of

forest land in 12 states, from West Virginia to Maine. Findings were published for each state as soon as data had been computed and analyzed. The field work for the initial survey was completed in 1958.

The initial survey utilized a double-sampling system devised by C. Allen Bickford. Photo sample plots were printed on aerial photos for each state. Each plot was photo-interpreted and classified into volume strata. A sample of photo-interpreted (P.I.) plots in each volume stratum were established in the field as ground plots. Then field crews went into the woods to locate each sample ground plot and record data on tree species, tree measurements, other tree characteristics, land use, and other area attributes.

Research in techniques in the late 1950s and early 1960s resulted in the implementation of a sampling design known as *Sampling with Partial Replacement* (SPI). This calls for the remeasurement of only a portion of the ground plots in a state from the initial survey and the utilization of new photos with new P.I. plot stratification and new ground plots. Thus, with the regression technique, there is full utilization of all the photo and ground plot information from the previous surveys.

During this time, Station personnel developed a sophisticated data-processing system, FINSYS, to process, compile, and analyze the large volume of forest-inventory data. The new sampling design and data-processing system were first used by the Station in the resurvey of West Virginia. Now FINSYS is used throughout the Americas and Europe in the processing of forest-inventory statistics.

Development of the necessary programs and personnel capability for electronic data processing has made it possible for the forest survey to calculate quickly and efficiently forest-area and timber-volume statistics and the associated sampling errors for each statistic. This was done for the resurvey of each state. The resurvey of all 14 states in the Northeast (100,300 acres of commercial forest land) was completed in 1972. The third survey of the Northeastern States is now under way.

The forest survey has been helped by cooperation from state agencies and forest industries, who have provided funds, manpower,



Forestry esthetics. The bank of trees (left) screens from sight the coal-mine spoils around this Anthracite Region town in Pennsylvania. Step through the screen of trees and you will see (right) the barren spoil banks.



To speed installation of new flooring in urban rehabilitation, a floor-leveling device was developed at the Laboratory at Princeton, West Virginia. New floor screeds are held in place over the old sagging floor, and plastic foam is sprayed under them to hold them in level position and bond them to the old floor.



The first research facility of the Allegheny Station. Built on the Ockanickon tract, this building was later moved to the Lebanon Experimental Forest in New Jersey. 1937.



One of the Northeastern Station's modern facilities. This is the Forest Insect and Disease Laboratory at Hamden, Connecticut.

aerial photographs, and information about forest-land ownership and timber-product output.

As a supplement to the forest-survey reports, the survey staff has made periodic reports on timber industries of different states, comparing industrial wood-use statistics with previous surveys and noting important trends in industrial development and wood use. Also, the staff compiles, analyzes, and reports the annual pulpwood production by states.

Forest Engineering

Forest engineering has long had a place in Station research. In his early work in logging and sawmilling, Fred Simmons incorporated many aspects of forest engineering: construction of logging roads, cable-logging systems, and the many devices and machines used in logging and sawmilling.

Forest engineering research was formally made a regular part of the Station program in 1964, when a forest engineering research unit was established in cooperation with West Virginia University at Morgantown, West Virginia, where, a few years later, a research laboratory was constructed.

The Station's forest engineering unit was established to study problems in getting logs from the woods to the road. Research has been concerned both with reducing logging and hauling costs and reducing the impact of logging on the environment.

Much of this research has centered on machines. Studies have been made to compare different types of commercially available tractors, to determine the tractor characteristics most desirable for skidding logs. Another problem tackled was rubber tractor tires—one of the big costs for loggers.

One logging device now under test at the Morgantown Laboratory is the CHUBALL, which was invented at our Princeton, West Virginia Laboratory for hauling logs up steep slopes. The CHUBALL is a large split steel ball—like a giant yo-yo—that can be rolled down the slope to where the logs are, dragging with it a cable from the tractor on the landing above. Then the ball and logs are hauled up the slope around trees and stumps and over brush to the landing. The engineers believe

the CHUBALL has promise and may require only half the logging roads needed for conventional systems—an environmental plus.

Wildlife Habitat

The first full-fledged wildlife-habitat research project was centered at Warren, Pennsylvania in 1959, and after 1965 at Morgantown, West Virginia. In the 1960s the Station's research revealed that, with certain precautionary measures, some wildlife, like deer and wild turkeys, actually benefit from a mixture of forest and openings created by cutting. The coordination of wildlife-habitat and timber management has helped to minimize browsing damage to forest reproduction.

A major concern is the relationship between timber and wildlife, and methods needed to coordinate the management of these two resources are being studied. Most studies so far have been concentrated on deer (at Warren) and on turkeys and squirrels (at Morgantown). In some of the early research, methods for studying these animals were developed.

One study now under way deals with the ecology of woody plants that provide food and cover for wildlife. Wildlife research is being more closely integrated with research in the other forest-resource disciplines—timber, water, recreation, and economics.

Recreation

As early as 1938, the Allegheny Station staff saw a potential for recreation use in the forests of the Middle Atlantic States. They recommended that methods be developed for expressing in dollars and cents the "so-called intangibles of forest value—the services rendered from the forest as recreation grounds and watershed protection," as a basis for decisions about forest uses.

The time was not ripe then for recreation research. But meanwhile the growing populations of the seaboard metropolitan areas—Boston, New York, Philadelphia, Baltimore, Washington—put increasing pressures on the forest lands for recreational use. Year by year the pressures grew.

In 1959 the Station—then the Northeastern Station—began to survey the region's most pressing recreation problems. In June 1959

the Station's Advisory Committee devoted its annual meeting to needs for recreation research. Dick Lane, then division chief for timber-management research, prepared a regional analysis of the problem.

In August 1959 the Station established the first Forest Service research unit to investigate problems of forest recreation. Centered at Warren, Pennsylvania, near a National Forest recreation area, this unit started out modestly with studies of design and facilities for campsites and picnic areas. Later they studied use fees, impact of people on the environment, management of ground cover, and recreation carrying capacity of wild lands.

In the reorganization of 1966, the Warren unit and the Central States Station's research unit at Berea, Kentucky, were consolidated and moved to headquarters on the campus of the State University of New York College of Forestry at Syracuse. Later the original Warren recreation research unit was moved to Durham, New Hampshire.

Research is designed to help managers of both public and private campgrounds improve their facilities and their use of the land. Because most recreation areas are privately owned, attention is being focused on them. Besides campgrounds, Station researchers have studied lands bought or leased for special uses such as hunting clubs and fishing rights.

Some attention has been given to regional planning. In cooperation with the University of Maine Cooperative Extension Service, a survey was made and a planning guide was prepared for developing outdoor recreation facilities in Washington County, Maine.

More and more, attention in recreation research has shifted from physical facilities to people, to what people need and want and expect from outdoor recreation. Social and economic aspects of recreation have come to the fore.

Studies were made to find out what makes a campground successful, to help managers bring their facilities into line with what people want. It was established that water—lakes and streams—contribute to the success of a recreation area.

One series of surveys, spanning 8 years, is the only long-term study of people's shifting

leisure interests ever conducted. This panel study, begun in 1964, documented a number of important trends in camping participation patterns.

The Station has recently added another first to its recreation-research program with the publication of a nation-wide survey of the camping market's potential for further growth. This study provides the first National profile of a rapidly expanding leisure market, which is now estimated to include nearly one-half of all United States households as past, present, or future campers.

The demands on forest land for recreation use are expected to increase, and this may impel the Station to intensify its recreation research. As an aid to planning ahead, the Station in 1971 sponsored (with the State University of New York College of Environmental Science and Forestry) a Forest Recreation Symposium at Syracuse, covering the planning, development, and management of recreational resources as well as socio-economic study of recreationists.

Environmental Forestry

Knowledge of ecology and concern for environment have always been implicit in Forest Service research and in the basic policy that the purpose of forestry is to manage the land for the benefit of the people—whether they live in urban, suburban, rural, or forested areas.

Concern for environment was evident in the Allegheny Station's early studies of the Anthracite Region of Pennsylvania. In the 1950s and 1960s this concern could be seen in studies to find ways to revegetate coal-mine spoil banks. Trees were tested for screening coal-region towns from unsightly mine spoils; and areas were surveyed and mapped to locate places where screens of trees could be used for this esthetic purpose.

Creation of a regular program of environmental forestry by the Station was a response to mushrooming public concern in recent years about man's deteriorating environment. This program got under way in 1970, when the Pinchot Institute for Environmental Forestry Research was established.

In the early 1960s the Milford, Pennsylvania, estate of Gifford Pinchot, first chief of

the U.S. Forest Service, had been donated to the Forest Service. In 1963 President John F. Kennedy personally dedicated the Pinchot Institute for conservation studies. In July 1970, management of the estate was transferred from the Washington office to the Northeastern Station.

Thus the Milford estate became the focal point for the Station's new Pinchot Institute for Environmental Forestry Research. The Institute was designed to act as a catalyst for research into forest-environment problems common to the urban-forest interface in the densely populated megalopolis that stretches from Boston to Washington. Its main purpose is to find ways in which forest resources can be used to improve the human environment in and around the urban centers of the Northeast.

Consistent with the cooperative nature of Forest Service research, the Institute provides research grants to a consortium of nine leading universities and research institutes of the Northeast. Approximately half of the Forest Service funding for the Institute is used for research by the Station; the other half is granted to consortium members. The Station established two new research units—at Amherst, Massachusetts, and Pennington, New Jersey—to carry out its part of the research.

The Institute's scientists are studying ways to establish and maintain stands of trees and

other plants in urban and suburban settings. It has been demonstrated that plants—especially trees—can improve the metropolis environment. They ameliorate the microclimate: reduce temperature, affect light intensity, reduce humidity, filter out air pollution, abate noise, and change air movements. Esthetically, they provide the greenery, shade, flowers, and natural wildlife habitat that make the difference between tedium and pleasant living.

Woodlands that surround urban areas and are interspersed in suburban areas are also vital to water needs. Vegetation protects watersheds against erosion and protects the water supply. Station scientists are learning how urban water supplies can be increased through judicious cutting and species manipulation on watersheds.

Wildlife is important too. One Station project is concerned with developing urban areas to attract and maintain wildlife. Preliminary studies in the Boston area have shown that city cemeteries not only provide the only open space in some urban areas, but also provide habitat for a surprisingly large variety of wildlife. Detailed plans have been published, showing how a backyard can be developed, stage by stage, to attract and provide habitat for a variety of birds, small mammals, and other wildlife.



This mobile device was developed at the Delaware, Ohio, Laboratory for X-raying living trees as an aid to insect and disease research.

PUTTING RESEARCH RESULTS TO USE

In the early days, when the old Northeastern and Allegheny Stations were small, the directors and scientists published many articles and papers to describe their work and report their findings. In 1946, when the Station was beginning to expand, director Harper recruited a professional writer-editor, the start of an editorial staff to speed the research results into publication.

A small editorial and publications staff was built up that during the years has helped the Station scientists get their works published—sometimes more than 200 a year—in scientific journals throughout the world as well as in trade journals, popular periodicals, Department of Agriculture and Forest Service series, in newspapers, and on radio and television.

Besides these outside publications, the Station publishes its own series of research papers and notes. For a long time the Station maintained its own printing plant, but since 1970 its printing has been done through the Government Printing Office.

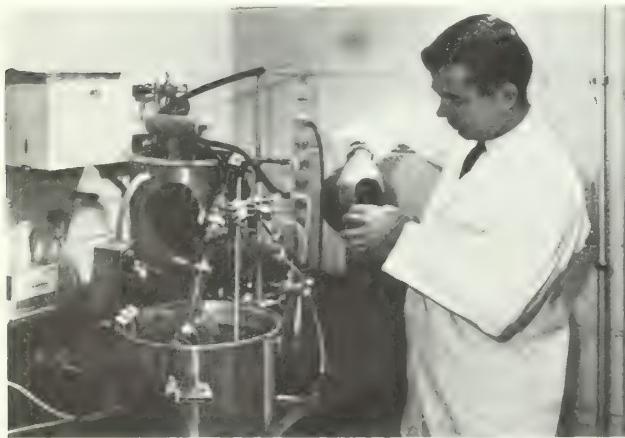
Station scientists have been active in making public their own research findings through talks at professional society meetings, local service clubs and civic organizations, at schools and at university seminars, on radio and television, and at demonstrations and

field trips for a broad variety of interested groups.

In 1966 an information service was established by Director Lane, and public information specialists were recruited to broaden the dissemination of research results through the mass media—newspapers, magazines, television, radio, films, demonstrations, and displays—to help the general public understand and support Forest Service efforts.

The close association between the Experiment Station and the State and Private Forestry area office, stemming mainly from the reorganization of 1966, was another effective step toward getting research results put to use. And last but not least, the Advisory Councils and Committees have steadily contributed toward this end.

The Station maintains its own library as a service to researchers and in 1961 recruited a professional librarian. Besides maintaining a collection of reference works and periodicals, the library assists scientists in obtaining bibliographic material through its inter-library loan arrangements and knowledge of a wide variety of information sources. The library also aids in the dissemination of Station research findings by maintaining a complete file of Station publications for loan or reproduction when copies are no longer available for distribution.



Laboratory work at Delaware, Ohio.

SUMMING UP

The Northeastern Forest Experiment Station has come a long way in the past 50 years. Two small experiment stations—each with a handful of scientists—were combined during World War II to create a new Northeastern Forest Experiment Station that has steadily grown to a size and complexity far beyond what anybody might have envisioned in 1923.

From a few projects in timber management, forest protection, economics, and genetics, the Station has grown to encompass research into almost every use of forests known to man. Scientists have been recruited from a score of different disciplines to carry out the multiple-use research called for by the complex demands made on our forest lands by the people of our nation.

Biometricians and statisticians have been added to the staff to help plan experiments

and analyze results. Editors and public-information people have been added to speed publication of results and inform the general public. Library facilities have been developed. Management analysts have been recruited to systematize operations in a number of activities. The most modern electronic computers have been used for storing, sorting, and retrieving data; and computer programs have been devised in many studies for analyzing data.

Tomorrow will no doubt bring new demands and pressures on our forests—one of the few renewable natural resources our nation has, and one that man cannot do without. The Station will respond to these needs, as it has in the past, in the hope that its research efforts will continue to contribute toward the wise use of this great natural resource—our forests.



Forest engineering research. Much of this research deals with the machines used to bring logs out of the woods.



These young wild turkeys are being studied in a wildlife-habitat project.

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Other Sources of Information

In addition to the published works cited above, a number of unpublished Forest Service office reports were referred to in the preparation of this history. Information was also obtained from tape-recorded oral-history interviews conducted by Elwood R. Maunder and Susan R. Schrepfer of the Forest History Society. Interviews were conducted with Samuel T. Dana, C. Edward Behre, Walter H. Meyer, Verne L. Harper, Hardy Shirley, and Warren T. Doolittle.

PERSONNEL

The following list of personnel who have served at the old Northeastern, Allegheny, and present Northeastern Forest Experiment Stations includes mainly professional people, plus others who have contributed significantly to Station programs and publications.

- Akcerman, P. E.
Adams, Edward L.*
Afanasiev, Michel
Allen, Rufus H., Jr.*
Amidon, Elliot L.
Anderson, A. H.
Anderson, Robert B.*
Araman, Philip B.*
Archer, Donald H.
Arner, Stanford L.*
Atkinson, Oscar L.*
Aubertin, Gerald M.*
Auchmoody, Luther R.*
Bain, Robert, assistant director,
 Support Services
Baird, J.
Banks, Wayne G.
Bard, George L.
Barger, Jack H.*
Barnard, Joseph E.*
Barraclough, Solon L.
Barrett, Harold J.
Baumgras, John E.*
Bean, James L.*
Behre, C. Edward, director
 1929-41
Belotelkin, Konstantin T.
Berg, William A.
Berry, Frederick H.*
Bethlahmy, Nedavia
Bevan, Arthur
Bickford, C. Allen
Biller, Cleveland J.*
Bjorkbom, John C.*
Bloom, Jerry H.*
Blum, Barton M.*
Blythe, Richard H., Jr.
Boardman, Steven
Bolich, G.

Bones, James T.*
Borneman, Willis T.
Bowers, Teresa M.*
Boyce, John S., director
 1928-29
Bradley, Dennis P.
Brandner, H. Phil
Brandt, Robert W.
Bratton, Allen W.
Brisbin, Robert L.*
Brock, Samuel M.
Bromfield, K.
Brown, J. Willcox
Brown, Raymond C., chief, Division of
 Forest Insect Research
Brush, Robert O.*
Burke, Hubert D.
Burnham, Chester F.
Burns, Denver P.
Buttrick, John
Callahan, K.
Camp, Harry W., Jr.
Campbell, Robert W.*
Cannon, William N., Jr.*
Caporaso, Allessio P.
Carl, Clayton M., Jr.*
Carlson, Tony C.
Carpenter, Roswell D.*
Carter, Roy M.
Cavallero, John B.
Cawelti, Stephen W.
Champagne, E. Garth
Chapman, Roger C.
Charlton, John W.
Church, Thomas W., Jr.*
Clark, Kenneth M.
Cole, Alexander B.
Corbett, Edward S.*
Cosenza, Benjamin J.
Craft, Edward P.*
Crosby, David
Crow, Alonzo B.
Croxton, Ralph J.
Cunningham, Frank E.
Cuppett, Donald G.*
Curry, John R.
Curtis, Brian M.
Curtis, Robert O.
Curtis, Willie R.*

*Still with the Station

- Cuthbert, Roy A.*
 Czapowskyj, Miroslaw M.*
 Dale, Martin E.*
 Dana, Samuel T., director
 1923-27
 Davidson, Walter H.*
 Davis, Grant*
 DeBald, Paul S.*
 DeGraaf, Richard M.*
 Demeritt, Maurice R., Jr.*
 Dempsey, Gilbert P.*
 Despard, Thomas L.*
 Dickerman, Murlyn B.
 Dickerson, A. Laverne*
 Dickson, David R.*
 Diebold, Charles H.
 Dieckhaus, James W.
 Diller, Jesse D.
 Dochinger, Leon S.*
 Dodd, Alfred N.
 Donley, David E.*
 Donnelly, John R.
 Doolittle, Warren T., director
 1970-*
 Dorr, Frederick J.
 Doverspike, George E.
 Dowden, Philip B.
 Dowdle, Barney
 Dubois, Normand R.*
 Dubois, Warren J.
 Duffield, John W.
 Duffy, Bernard F., assistant
 director, Support Services*
 Eads, Larry D.
 Echelberger, Herbert E.*
 Edgerton, L. J.
 Ellefson, Paul V.
 Ellen, J. David
 Ellsbury, Wendell M.
 Elliott, Terry L.
 Ellstrom, Raymond
 Emanuel, David M.*
 Eschner, Arthur
 Etter, Daniel O., Jr.*
 Fahnestock, George R.
 Farver, James T.
 Federer, C. Anthony*
 Fenton, Richard H.
 Ferguson, Roland H.*
 Ferree, Miles J.
 Filip, Stanley M.*
- Fogerty, Virginia M.*
 Folsom, John B.
 Foote, Dean A.*
 Forbes, Reginald D., director,
 Allegheny Forest Experiment
 Station, 1927-39
 Fowler, Marvin E., chief,
 Division of Forest Disease Research
 Frampton, Lois C.
 Frank, Robert M., Jr.*
 Franz, George J., Jr.
 Frayer, Warren E.
 Frost, Richard E.*
 Furnish, James R.
 Furnival, George M.
 Gabriel, William J.*
 Galford, Jimmy R.*
 Gammon, Glenn L.*
 Gansner, David A.*
 Garrett, Lawrence D.*
 Garrett, Peter W.*
 Gast, P. R.
 Gatchell, Charles J.*
 Gedney, Donald R.
 Gentry, Claude E.*
 Gerhold, Henry H.
 Gibbs, Carter B.
 Gibson, Harry G.*
 Gibson, Lester P.*
 Gilbert, Adrian M.
 Gill, John D.*
 Gingrich, Samuel F.*
 Girard, James W.
 Gochenour, Donald L., Jr.*
 Godwin, Paul A.*
 Goodell, Bertram C.
 Gordon, Barry D.*
 Gruber, Raymond E.*
 Greene, Mary T.
 Gregory, G. Robinson
 Gregory, Garold F.*
 Gregory, Robert*
 Grisez, Ted J.*
 Griswold, Frank S.
 Griswold, Norman B.
 Grossman, Sidney J.
 Grove, Gerald H.
 Gyure, Benjamin L.
 Hagenstein, Perry R.
 Haggard, Paul L.
 Hahn, Glenn G.

Hamilton, Thomas E., assistant
director, Division of Forest
Economics, Survey, Marketing &
Utilization*

Hampf, Frederick E.

Hanks, Leland F.*

Hansbrough, John R., chief,
Division of Forest Disease Research

Hansen, Bruce G.*

Harper, Verne L., director,
1946-50

Hart, Arthur C.

Hart, George E., Jr.

Hartley, Carl

Hartman, Fred J.

Hartman, Robert L.

Hastings, Arthur R.

Hatch, A. B.

Hay, Cyrus J.*

Hazen, J. F.

Healy, William M.*

Heisler, Gordon M.*

Herrick, John W.*

Herrick, Owen W.*

Hicks, Halsey M.

Hirt, Ray R.

Holcolm, Carl J.

Holt, William R.

Homeyer, Jay W.*

Horsley, Stephen B.*

Hornbeck, James W.*

Hough, Ashbel F.

Houston, David R.*

Howard, John*

Howard, Lance F.*

Howe, George E.

Hoyle, Merrill C.*

Huberman, Morris A.

Huntzinger, Harold J.

Hutchins, Lee M.

Hutnik, Russell J.

Huttinger, William O.

Huyler, Neil K.*

Ineson, Frank A., chief,
Division of Forest Economics

Jacot, Arthur P.

Janerette, Carol A.*

Jaynes, Harold A.

Jensen, Chester E.

Jensen, Keith F.*

Jensen, Victor S.

Johnson, Leonard R.*

Jones, Clark A.

Jones, Thomas W.*

Jordan, James S.*

Jorgensen, Richard N.

Kasiak, Edward

Katz, Barbara E.*

Kawelti, Stephen W.

Kelley, A. P.

Kendig, Thomas E.

Kennedy, Bruce H.*

Kenney, Robert J.

Kidd, Walter J., Jr.

King, Robert

Kingsley, Neal P.*

Klawitter, Ralph A., assistant
director, Division of Insect
and Disease Research

Klein, E. Lawrence

Knutson, Robert G.*

Kochenderfer, James N.*

Koelling, Melvin R.

Koenick, Leonard J.

Kraemer, J. Hugo

Krochmal, Arnold

Lane, Richard D., director,
1966-70

LaPage, Wilbur F.*

Large, Hollis R.*

Larsen, David N.*

Larson, Edwin vH.*

Lavigne, Raymond W.

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Leak, William B.*

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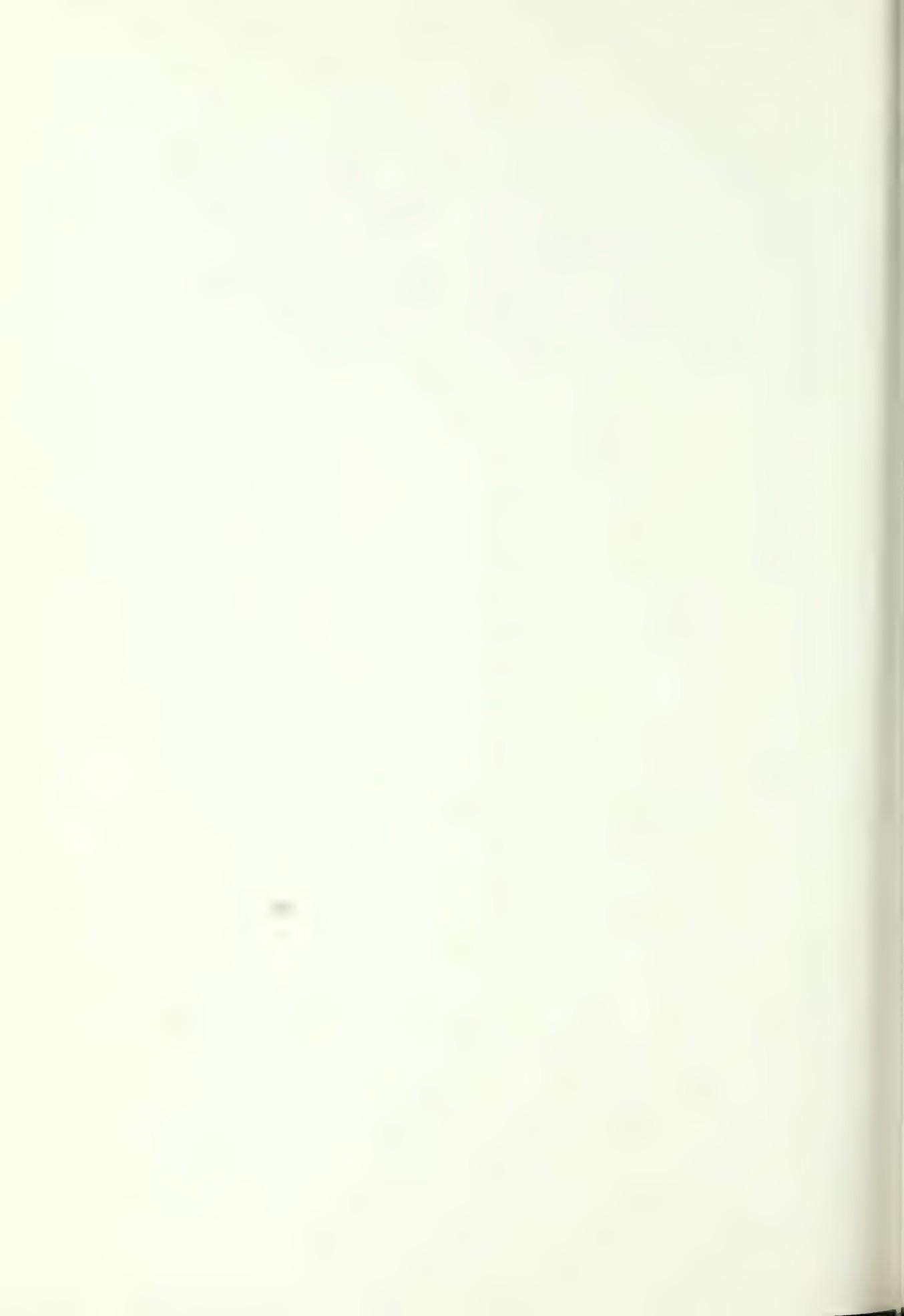
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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

by A. Jeff Martin
and Paul E. Sendak

OPERATIONS RESEARCH IN FORESTRY: A BIBLIOGRAPHY



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FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
6816 MARKET STREET, UPPER DARBY, PA. 19082
WARREN T. DOOLITTLE, DIRECTOR

The Authors

A. JEFF MARTIN attended Michigan State University, receiving a degree in forestry in 1965, an M.S. degree in forest management in 1966, and a Ph.D. degree in forest management in 1969. He joined the staff of the Northeastern Forest Experiment Station at the Forest Products Marketing Laboratory, Princeton, West Virginia, in 1969. He is conducting research in the marketing of primary wood products, the application of system-analysis procedures to the transportation of Appalachian roundwood products, and logging residue.

PAUL E. SENDAK received his B.S. degree in forestry from Rutgers University in 1965. He received his M.S. degree in forestry in 1968 and his Ph.D. in forestry economics in 1972 from the University of Massachusetts. He joined the Northeastern Forest Experiment Station in 1969 at the Forest Products Marketing Laboratory in Princeton, West Virginia. He is now working in the Maple Products Marketing Project at the Experiment Station's Sugar Maple Laboratory in South Burlington, Vermont.

OPERATIONS RESEARCH IN FORESTRY: A BIBLIOGRAPHY

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INTRODUCTION

ONE WHO CONSULTS the literature sources today is struck by the increasing amount of attention paid to operations research in forestry and forestry-related fields. We are living in the computer age at a time when operations research confronts us almost continuously, yet it is also a time when many managers and researchers are just getting their hands wet in this pool of quantitative techniques.

Operations research is one of the most comprehensive approaches to problem solving. It embraces a number of analytical techniques sharing certain common characteristics. Ackoff and Sasieni (1968) have defined the operations-research approach as: "(1) The application of scientific method, (2) by interdisciplinary teams, (3) to problems involving the control of organized (man-machine) systems so as to provide solutions which best serve the purposes of the organization as a whole."

Operations research is known by a variety of names: operational research — or simply OR — operational analysis, operation evaluation, systems analysis, systems research, management science, and others.

The operations-research analyst customarily formulates his problem in terms of a mathematical model. Many of these models have been generalized and adopted for problem solving by scientists in a variety of disciplines. Some OR models have been developed and applied to such a great extent that they are considered important subject matter in them-

selves. The linear programming model is an example.

The table of contents of any introductory operations research text provides a list of OR techniques. Included among the techniques applied to forestry problems are the Bayesian approach to decision-making, decision trees, dynamic programming, linear programming, integer programming, parametric programming, input-output analysis, Markov processes, Monte Carlo and other simulation techniques, management games, PERT, queuing models, and inventory models.

The purpose of this bibliography is to aggregate the literature sources (prior to 1971) concerned with OR applications to problems involving forest-produced goods and services. The major classes of forest products include wood products; other plant products, such as maple syrup and naval stores; animal products, both domestic and wild; forest-oriented recreation environment; and water resources.

An important decision criteria for evaluating a source is its emphasis on the forest or forest product. Therefore we excluded material with little or no emphasis on the forest resource. Exceptions to this rule are certain texts and expository publications that, although not related to the resource, are considered excellent reference material for the OR-oriented manager or scientist.

The bibliography was printed by FAMULUS, a computer program maintained at the Computer Services Library, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

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8. ANONYMOUS. 1966. OPERATIONS RESEARCH: TOOL FOR GROWTH AT BOISE CASCADE. FOREST PROD. J. 16(2):6-7. BOISE CASCADE IS APPLYING OPERATIONS-RESEARCH TECHNIQUES TO CUT WASTE TO GET THE MOST OUT OF PRODUCTION OPERATIONS, AND TO CREATE THE BEST VALUE FROM THE BASIC RAW MATERIAL.
9. ARIMIZU, T. 1956. (APPLICATION OF LINEAR PROGRAMMING TO FORESTRY.) TOKYO UNIV. FOR., MISC. INFORM. NO. 11, PP. 49-76. (IN JAPANESE WITH ENGLISH SUMMARY.) AN APPLICATION OF LINEAR PROGRAMMING TO AN ECONOMIC EVALUATION OF A SAWMILL AS AN ALTERNATIVE TO TRADITIONAL MARGINAL ANALYSIS. LP HAS CONSIDERABLE MERIT FOR LARGE MILLS, HOWEVER, THE GREATEST OBSTACLE TO ITS USE ARE THE REQUIREMENTS IN THE MODEL-BUILDING PHASE.
10. ARIMIZU, T. 1958. (WORKING GROUP MATRIX IN DYNAMIC MODEL OF FOREST MANAGEMENT.) JAP. FOREST. SOC. J. 40(4):185-190. THE FIRST STEP IN REACHING THE GOAL OF A DYNAMIC MODEL OF FOREST MANAGEMENT IS TO CONSTRUCT A WORKING GROUP MATRIX. ACTIVITY ANALYSIS IS THEN USED IN BUILDING THE DYNAMIC MODEL.
11. AKVANITIS, L. G. 1966. DECISION RULES FOR DESIGN OF FOREST SAMPLING SYSTEMS: A CONTRIBUTION TO

- METHODOLOGY BASED ON COMPUTER SIMULATION. DISS. ARSTR. 27B(3):658-659. THE STUDY WAS DESIGNED TO SHOW THE USE OF A COMPUTER SIMULATION METHOD IN DETERMINING FOREST SAMPLING EFFICIENCY. THE RESULTS PROVIDE LIMITED ANSWERS TO THE PROBLEM OF OPTIMUM COMBINATION OF NUMBER AND SIZE OF PLOTS IN SAMPLING FORESTS, AND STRESS THE VALUE OF INTRODUCING CONCEPTS FROM PRODUCTION ECONOMICS, AND USING SIMULATION AND COMPUTERS.
12. ARVANITIS, L. G., AND W. G. O'REGAN. 1967. COMPUTER SIMULATION AND ECONOMIC EFFICIENCY IN FOREST SAMPLING. HILGARDIA 38(2):133-164. SIMULATION TECHNIQUES WERE USED TO OBTAIN VARIANCE FUNCTIONS FOR VARIOUS PARAMETERS AND FORESTS. TO SOLVE THE PROBLEM OF MAXIMIZING INFORMATION ABOUT A POPULATION, UNDER A FIXED-BUDGET CONSTRAINT; OR THAT OF A SPECIFIED AMOUNT OF INFORMATION AT MINIMUM COST, THE AUTHOR DEVISED COST FUNCTIONS FOR EACH ESTIMATE, AND ECONOMICALLY EFFICIENT SAMPLING PLANS WERE THEN DEVELOPED.
13. ARVANITIS, L. G., AND W. G. O'REGAN. 1969. SAMPLING SIMULATION COMPUTER PROGRAMS. I. FIXED AND VARIABLE PLOTS. UNIV. WISC. COLL. AGR. & LIFE SCI. RES. REP. 49, 48 PP. MADISON. A FORTRAN PROGRAM IS PRESENTED THAT IS CAPABLE OF SIMULATING EQUAL AND VARIABLE PROBABILITY SAMPLING RULES APPLICABLE TO FOREST, RANGE, AND RELATED INVENTORIES. BASED ON A LOCATIONAL MAP OF THE ELEMENTS; AND INPUT INFORMATION ON THE VARIABLES OF INTEREST, THE PROGRAM INSTRUCTS THE COMPUTER (1) TO IDENTIFY CLUSTERS OF ELEMENTS ASSOCIATED WITH A NUMBER OF POINTS AND (2) TO CONSTRUCT WEIGHTED MEASUREMENTS AT THOSE POINTS AND VARIANCES AMONG POINT MEASUREMENTS.
14. ATROHIN, V. G., AND A. M. KOROTKOV. 1967. (REGULATION OF STAND COMPOSITION BY MEANS OF THINNINGS.) LESN. Z., ARHANGEL'ISK 10(2):10-13. (IN RUSSIAN.) LINEAR PROGRAMMING IS USED IN MAKING THINNING DECISIONS (ON WHICH AND HOW MANY TREES TO REMOVE), WITH EXAMPLE DATA FROM AN 18-YEAR-OLD STAND OF OAK, ASPEN, BIRCH, AND SPRUCE (TOTAL VOLUME 57.6 CU. M/HA., 10,060 TREES/HA.). FOR A 40-PERCENT THINNING (BY NUMBER OF STEMS), THE LP METHOD SHOWED THAT 380 BIRCH AND 3,620 ASPEN/HA. SHOULD BE REMOVED.
15. BAMPING, J. H., AND J. L. CLUTTER. 1964. COST EFFICIENCIES IN A FOREST ENTERPRISE. COST CONTR. IN SOUTH. FORESTRY. (ED. BY R. W. MCDERMID, 13TH ANNU. FORESTRY SYMP.: 35-43.) 131 PP. BATON ROUGE:

- LA. STATE UNIV. PRESS. TECHNIQUES GENERALLY REFERRED TO AS OPERATIONS RESEARCH AND SYSTEMS ANALYSIS USED IN THE SELECTION OF A PROGRAM UPON WHICH FUNDS ARE TO BE EXPENDED, AND THE EXECUTION OF THE PROGRAM AT MINIMUM COST CONSISTENT WITH MAXIMUM EFFECTIVENESS IN A FOREST ENTERPRISE, CAN BE PRACTICABLE ONLY WHEN OFFERED AS A COMPLEMENT TO JUDGMENT AND INTUITION.
16. BARE, B. B. 1969. THE DEVELOPMENT AND EVALUATION OF A FOREST MANAGEMENT GAME. PH.D. DISS., PURDUE UNIV., LAFAYETTE, IND. THE PRIMARY OBJECTIVE OF THIS STUDY WAS DEVELOPMENT OF A COMPUTERIZED FOREST MANAGEMENT GAME THAT WOULD PROVIDE FORESTRY STUDENTS WITH AN OPPORTUNITY TO VISUALIZE THE OPERATIONAL PROBLEMS OF THE FOREST MANAGER FROM THE TOTAL SYSTEM POINT OF VIEW. AN EVALUATION WAS MADE OF THE EDUCATIONAL VALUE OF THE GAME FOR TEACHING BIOLOGICAL AND FINANCIAL INTERRELATIONSHIPS, OF THE EFFECTIVENESS OF SELECTED CRITERIA FOR MEASURING GAME PERFORMANCE, AND OF THE ROLE OF INVENTORY INFORMATION AS IT Affected MANAGERIAL PERFORMANCE.
17. BARE, B. B. 1970. PURDUE'S FOREST MANAGEMENT GAME. J. FOREST, 68(9):554-557. SYSTEMS ANALYSIS IS VERY EFFECTIVE IN DETERMINING THE OVERALL EFFECT OF BIOLOGICAL AND FINANCIAL DECISIONS ON A TOTAL FOREST-MANAGEMENT SYSTEM. THE USE OF A COMPETITIVE SIMULATION MODEL IN TEACHING ENABLES STUDENTS OF FOREST MANAGEMENT TO VISUALIZE THE OPERATIONAL PROBLEMS OF THE FOREST MANAGER FROM THE TOTAL SYSTEMS POINT OF VIEW.
18. BARE, B. B., AND E. L. NORMAN. 1969. AN EVALUATION OF INTEGER PROGRAMMING IN FOREST PRODUCTION SCHEDULING PROBLEMS. PURDUE UNIV. AGR. EXP. STA. RES. BULL. 847, 7 PP. LAFAYETTE, IND. A NEW INTEGER PROGRAMMING ALGORITHM IS APPLIED TO FORESTRY PROBLEMS DEALING WITH THE PREPARATION OF CUTTING SCHEDULES. TWO SMALL EXAMPLE PROBLEMS ARE DISCUSSED AND EVALUATED WITH THIS TECHNQUE.
19. BAXTER, H. O. 1969. IMPLICATIONS AND RECOMMENDATIONS FOR THE USE OF OPERATIONS RESEARCH FOR SAWMILL MANAGERS. OPER. RES. APPL. TO SAWMILLS. PROC.: 57-63. UNIV. GEORGIA, ATHENS. OPERATIONS RESEARCH SEEMS FEASIBLE FOR CONTINUOUS APPLICATION TO LARGER SAWMILLS AND FOR PERIODIC USE BY SMALLER ONES. IMPLEMENTATION OF OPERATIONS RESEARCH INVOLVES DEVELOPING THE INITIAL STUDY, MAINTAINING A CURRENT MODEL, DEVELOPING RECOMMENDATIONS FROM COMPUTER SOLUTIONS, AND

IMPLEMENTING THE RECOMMENDATIONS.

20. BAXTER, H. O., 1969. SIMULATION CAPABILITIES WITHIN THE BASIC LINEAR PROGRAMMING MODEL. OPER. RES. APPL. TO SAWMILLS, PROC.: 31-43. UNIV. GEORGIA, ATHENS. AFTER THE BASIC LINEAR PROGRAM HAS BEEN DEVELOPED, IT IS POSSIBLE TO DETERMINE THE EFFECTS OF ANTICIPATED OR PROPOSED CHANGES BY SIMULATING THEM IN THE MODEL. CHANGES IN THE LEVEL OF LOG INPUT, EFFECTIVE OPERATING TIME PER HOUR, PRICE OF OUTPUTS, AND IN MILL LAYOUT AND EQUIPMENT ARE SIMULATED.
21. BELLMAN, R. 1957. DYNAMIC PROGRAMMING. 342 PP., ILLUS. PRINCETON, N. J.: PRINCETON UNIV. PRESS. THIS IS THE PIONEERING BOOK ABOUT DYNAMIC PROGRAMMING.
22. HENGSTON, S. J. 1966. A MATHEMATICAL MODEL FOR OPTIMUM TIMBER ALLOCATION. M.S. THESIS, OREG. STATE UNIV., CORVALLIS. LINEAR PROGRAMMING IS USED TO SOLVE A HYPOTHETICAL PROBLEM OF HOW MUCH COMPANY TIMBER AND HOW MUCH GOVERNMENT TIMBER SHOULD BE ALLOCATED TO A SAWMILL IN A GIVEN YEAR. OTHER OPERATIONS RESEARCH TECHNIQUES PRESENTED IN CONNECTION WITH THE ALLOCATION PROBLEM ARE POSTOPTIMALITY ANALYSIS AND REGRESSION ANALYSIS.
23. BENTLEY, W. R., AND H. F. KAISER, JR. 1967. SEQUENTIAL DECISIONS IN TIMBER MANAGEMENT: A CHRISTMAS TREE CASE STUDY. J. FOREST. 65(10):714-719. THE RELATIONSHIP OVER TIME OF PRODUCTION DECISIONS, CHANCE EVENTS, AND VALUE OUTCOMES IS PRESENTED AS A DECISION TREE. THE DECISION-TREE APPROACH HAS APPLICATION TO PRACTICAL TIMBER-MANAGEMENT PROBLEMS BECAUSE IT INTEGRATES TECHNICAL INFORMATION, ECONOMIC ANALYSIS, EXPERT OPINION, AND MANAGEMENT JUDGMENT.
24. BETHEL, J. S., AND C. HARRELL. 1955. THE APPLICATION OF LINEAR PROGRAMMING TO PLYWOOD PRODUCTION AND DISTRIBUTION. N.C. STATE COLL., SCHOOL OF FOR., RALEIGH. MIMED. ESSENTIALLY THE SAME MATERIAL AS FOUND IN THE FOLLOWING CITATION.
25. BETHEL, J. S., AND C. HARRELL. 1957. THE APPLICATION OF LINEAR PROGRAMMING TO PLYWOOD PRODUCTION AND DISTRIBUTION. FOREST PROD. J. 7(7):221-227. A LINEAR PROGRAMMING SYSTEM CAN BE USED TO ARRIVE AT OPTIMUM SOLUTIONS TO VARIOUS PLYWOOD PRODUCTION AND DISTRIBUTION PROBLEMS. A LINEAR PROGRAMMING SYSTEM IS SHOWN TO PROVIDE A QUANTITATIVE MEASURE OF THE COSTS OF ALTERNATIVE

PRODUCTION AND DISTRIBUTION PROCEDURES.

26. BETHUNE, J. E. 1967. FOREST OPERATIONS ANALYSIS: NEW APPROACH TO MANAGEMENT PLANNING. FOREST FARMER 26(5):16, 22, 23. A GENERAL DESCRIPTION OF SOME OPERATIONS-RESEARCH TECHNIQUES THAT CAN BE APPLIED TO FORESTRY ACTIVITIES, AND SOME POSSIBLE AREAS OF APPLICATION AND PROSPECTS FOR FUTURE USE.
27. BETHUNE, J. E. 1967. MATHEMATICAL PROGRAMMING APPROACHES TO THE ALLOCATION OF RESOURCES TO PUBLICLY SUPPORTED TIMBER MANAGEMENT RESEARCH. PH. D. THESIS, UNIV. GEORGIA, ATHENS. DIFFERENT MODELS ARE COMPARED FOR USE IN DEVELOPING A PLAN FOR ALLOCATING FUNDS IN THE FOREST-RESEARCH PROGRAM IN GEORGIA.
28. BETHUNE, J. E., AND J. L. CLUTTER. 1969. ALLOCATING FUNDS TO TIMBER MANAGEMENT RESEARCH. FOREST SCI. MONOG. 16, WASHINGTON, D. C. 22 PP. THIS STUDY SEEKS TO ADOPT AND DEVELOP QUANTIFIABLE CRITERIA AND OBJECTIVE METHODS TO ASSIST IN ALLOCATING FUNDS TO TIMBER-MANAGEMENT RESEARCH. REPRESENTATIVE ALLOCATION MODELS ARE ADAPTED TO PORTIONS OF THE PROBLEM OF ALLOCATING FUNDS TO FORESTRY RESEARCH IN GEORGIA. A DYNAMIC PROGRAMMING MODEL IS USED TO ALLOCATE RESEARCH FUNDS AMONG BROAD TYPES OF PROGRAMS.
29. BIOMETRICS - OPERATIONS RESEARCH SECTION. 1968. MAX - MILLION: A COMPUTERIZED FOREST MANAGEMENT PLANNING SYSTEM. UNIV. GEORGIA SCHOOL FOREST RES. 61 PP. ATHENS. THIS PUBLICATION CONTAINS INSTRUCTIONS FOR OPERATING AND INTERPRETING OUTPUT FROM A COMPUTERIZED FOREST MANAGEMENT PLANNING SYSTEM. THE COMPLETE SYSTEM IS COMPOSED OF TWO LARGE COMPUTER PROGRAMS. THE FIRST OF THESE CARRIES OUT CALCULATIONS OF AN APPRAISAL NATURE WHILE THE SECOND PERFORMS A SCHEDULING FUNCTION FOR HARVESTING AND REGENERATION USING LINEAR PROGRAMMING TECHNIQUES.
30. BOCHSBICHLER, K., AND H. SCHMOTZER. 1969. IS FORESTRY COMPETITIVE AS AN ECONOMIC ACTIVITY OF PEASANT FARMERS IN MOUNTAIN AREAS? MITT. FORSTL. VERSANST. WIEN. 85, 352 PP. IN GERMAN, SUMMARIES IN ENGLISH, FRENCH, AND RUSSIAN. A STUDY IN A RURAL MOUNTAIN VALLEY IN STYRIA, USING LINEAR PROGRAMMING TECHNIQUES FOR THE DEVELOPMENT OF MODELS. THOUGH MANY OF THE DATA HAD TO BE ESTIMATED ON THE BASIS OF GERMAN PUBLICATIONS, RESULTS SUGGEST THAT, FOR FARM HOLDINGS ON SLOPES, THEIR FORESTS ARE OF CONSIDERABLE

IMPORTANCE, AND EVEN AT LOW YIELDS ECONOMICALLY SUPERIOR TO GRASSLAND HUSBANDRY.

31. BUDT, J. C. G. 1967. MATHEMATICAL REASONING IN ECONOMICS AND MANAGEMENT SCIENCE. 178 PP. ENGLEWOOD CLIFFS, NEW JERSEY: PRENTICE-HALL BOOK COMPANY. CONTENTS: CHARACTERISTIC ROOTS AND VECTORS; DIFFERENCE EQUATIONS; ASSORTED PROBLEMS IN PROBABILITY THEORY; MARKOV CHAINS, DECISION CRITERIA, AND UTILITY CURVES; GAME THEORY; STRATEGIES; DYNAMIC PROGRAMMING; SENSITIVITY ANALYSIS; ELEMENTARY INVENTORY MODELS; GROWTH MODELS; LEONTIEF MODELS.
32. BOTWIN, M. 1966. (METHODS OF LINEAR PROGRAMMING AS APPLIED TO FORESTRY.) SYLWAN 110(2):17-25. (IN POLISH.) TWO EXAMPLES ARE PRESENTED FOR THE DETERMINATION OF AN OPTIMAL MANAGEMENT PLAN WITH THE AID OF LINEAR PROGRAMMING. THE AUTHOR INDICATES THAT MANY FORESTRY PROBLEMS CAN BE SOLVED WITH A VARIETY OF MATHEMATICAL METHODS.
33. BOUGHTON, W. C. 1967. PLANNING THE CONSTRUCTION OF FOREST ROADS BY LINEAR PROGRAMMING. AUST. FOR. 31(2):111-120. AN APPLICATION OF LP TO THE PLANNING OF FOREST ROAD CONSTRUCTION IS ILLUSTRATED. MOVEMENT OF EARTH FROM REGIONS OF EXCESS CUT TO REGIONS REQUIRING ADDITIONAL FILL IS ANALYZED AS AN ALLOCATION PROBLEM, AND AN OPTIMUM SOLUTION IS OBTAINED BY LINEAR PROGRAMMING. THE USE OF BORROW AREAS AND WASTE AREAS, IN ADDITION TO THE MOVEMENT OF MATERIAL FROM ONE SECTION OF THE ROAD TO ANOTHER, IS SHOWN TO BE EASILY HANDLED IN THE LINEAR-PROGRAMMING SOLUTION.
34. BRODIN, A., R. J. MCCONNEN, AND W. G. O'REGAN. 1965. SOME OPERATIONS RESEARCH APPLICATIONS IN THE CONSERVATION OF WILDLAND RESOURCES. MANAGE. SCI. 11(9): 802-814. FIVE EXAMPLES OF OPERATIONS RESEARCH APPLICATIONS ARE GIVEN. THE FIRST IS AN APPROACH TO THE PROBLEM OF MINIMIZING WILDLAND FIRE COSTS. THE SECOND CONCERN'S INSECT PEST CONTROL. A THIRD DEALS WITH THE APPLICATION OF LINEAR PROGRAMMING TO THE PROBLEM OF MANAGING A WILDLAND AREA AS A CONTINUING SOURCE OF ONE OR MORE PRODUCTS OR SERVICES. FINALLY, TWO EXAMPLES OF SIMULATION TECHNIQUES APPLIED TO FOREST MANAGEMENT AND FOREST SAMPLING ARE PRESENTED.
35. BROSS, IRWIN, D. J. 1953. DESIGN FOR DECISION. 276 PP., ILLUS. NEW YORK: MACMILLAN CO. A METHOD OF REACHING DECISIONS AND SOLVING PROBLEMS BY "STATISTICAL DECISION," WHICH COMBINES

PRINCIPLES DERIVED FROM SUCH AREAS AS THE THEORY OF GAMES, COST ACCOUNTING, INFORMATION THEORY, LOGIC, AND ECONOMICS IS DESCRIBED. FOLLOWING AN EXPLANATION THAT DECISION-MAKING INVOLVES: (1) PREDICTIONS AND A KNOWLEDGE OF PROBABILITIES, (2) VALUE JUDGMENTS, AND (3) CRITERIA FOR ACTION, THESE FACTORS ARE RELATED MATHEMATICALLY TO PROVIDE A SYSTEM OF DECISION MAKING APPLICABLE TO A WIDE VARIETY OF PROBLEMS. DETAILS OF MATHEMATICAL STATISTICS ARE AVOIDED IN FAVOR OF AN EXPLANATORY TREATMENT OF THE METHODS AND PROCEDURES IN REACHING DECISIONS USABLE NOT ONLY AS SCIENTIFIC METHOD, BUT ALSO IN COMMERCIAL AND SOCIAL PROBLEMS.

36. BROWN, K. M. 1969. A DENSITY DEPENDENT MODEL OF INDIVIDUAL TREE DEVELOPMENT. M.S. THESIS, PURDUE UNIV., LAFAYETTE, IND. THE DEVELOPMENT OF A TREE EXPRESSED AS RATE AND DISTRIBUTION OF GROWTH IS SIMULATED UNDER DIFFERENT STAND DENSITIES.
37. BUNCE, H. W. F. 1968. AN ANALYSIS OF FOREST REGULATORY CONCEPTS IN TERMS OF TECHNOLOGICAL AND SOCIAL DYNAMICS. DISS. ABSTR. 28(10):3949B. A DISCUSSION OF EXISTING METHODS OF DETERMINING THE ANNUAL CUT AND THE NEED FOR A NEW APPROACH THAT WILL CONSIDER CHANGES IN MARKET FACTORS AND TECHNOLOGY THAT MAY OCCUR DURING THE ROTATION. A PROPOSED MODEL, IN THE FORM OF A FLOW CHART, IS ALSO INCLUDED.
38. BUONGIORNO, J. 1969. EVALUATION OF ALTERNATIVE FOREST REGULATION METHODS: A LINEAR PROGRAMMING APPROACH. M.S. THESIS, STATE UNIV. N.Y. COLL. FORESTRY, SYRACUSE. LINEAR PROGRAMMING IS USED TO DETERMINE WHETHER THERE ARE CIRCUMSTANCES UNDER WHICH AN ADVANTAGEOUS ALTERNATIVE TO EVEN-FLOW MANAGEMENT EXISTS, SUCH AS ACCELERATED-CUT MANAGEMENT.
39. BURNS, R. 1964. SIMULATION OF TIMBER STAND STRUCTURES RESULTING FROM NATURAL SUCCESSION ON ABANDONED FARM LAND IN SOUTHERN NEW YORK. M.S. THESIS, STATE UNIV. N.Y., COLL. FORESTRY, SYRACUSE. A PRESENTATION OF A MONTE CARLO SIMULATION THAT ESTIMATES THE RESULTS OF MAKING LITTLE OR NO INITIAL INVESTMENT TO ESTABLISH THE TIMBER-GROWING PROCESS ON ABANDONED FARM LAND, THE METHOD, RATHER THAN THE RESULTING CONCLUSION, IS EMPHASIZED.
40. BUSSELL, W. H., ET. AL. 1969. PULPWOOD HARVESTING SYSTEMS RESEARCH AT AUBURN UNIVERSITY. FOREST

ENG. CONF. PROC. 1968:69-70, MICHIGAN STATE UNIV., E. LANSING. THE FIRST PHASE OF THE STUDY WAS DIRECTED AT IMPROVEMENT OF THE OPERATION OF LARGE EXISTING SYSTEMS, AND HAS BEEN DIVIDED INTO THREE SEGMENTS: (A) OPERATIONAL CHARACTERISTICS--USING A COMPUTER SIMULATION MODEL, (B) FINANCIAL ASPECTS--USING BREAK-EVEN ANALYSIS, AND (C) ORGANIZATIONAL ASPECTS OF SYSTEMS--ATTEMPTING TO PRODUCE A "SYSTEMS SYNTHESIZER". THE SECOND MAJOR PHASE OF THE AUBURN PROJECT IS CONCERNED WITH THE SYNTHESIS OF NEW SYSTEMS SPECIFICALLY DESIGNED FOR OPERATION UNDER THE CONSTRAINTS OF THE SOUTHEAST.

41. CARLSON, B. 1969. INCREASED PRODUCTION WITH LOGGING EQUIPMENT THROUGH COMPUTERIZED PLANNING. FOREST ENG. CONF. PROC. 1968:66-68, MICHIGAN STATE UNIV., EAST LANSING. THE PLAN IS FORMULATED AS A LINEAR PROGRAMMING PROBLEM. A 1-YEAR PLAN GIVES OPTIMUM STORAGE QUANTITIES AT LANDING AND MILL AND OPTIMUM TRANSPORT QUANTITY FOR EACH MONTH FOR LOGS AND PULPWOOD AND FOR EACH OF TWO GEOGRAPHICAL REGIONS.
42. CARR, C. R., AND C. W. HOWE. 1964. QUANTITATIVE DECISION PROCEDURES IN MANAGEMENT AND ECONOMICS. 383 PP. NEW YORK: McGRAW-HILL BOOK CO. CHAPTERS ON: FOUNDATIONS AND METHODS OF SINGLE-STAGE UNIVARIATE ANALYSIS, LINEAR PROGRAMMING, INTEGER PROGRAMMING, NONLINEAR PROGRAMMING, STEPWISE MAXIMIZATION, AND DYNAMIC PROGRAMMING.
43. CARROLL, C. W. 1960. AN OPERATIONS RESEARCH APPROACH TO THE ECONOMIC OPTIMIZATION OF A KRAFT PULPING PROCESS. TAPPI 43(4):305-312. A HYPOTHETICAL KRAFT PULPING PROCESS IS SIMULATED WITH A MATHEMATICAL MODEL TO MAXIMIZE NET DOLLAR RETURN FROM THE OPERATION.
44. CESARIO, F. J. 1965. MONTE CARLO SIMULATION OF SOME LOGGING OPERATIONS. M.F. THESIS, MONTANA STATE UNIV., MISSOULA. COST, PROFIT, AND WASTE MATERIAL WERE USED AS MEASURES OF EFFECTIVENESS IN THIS MONTE CARLO SIMULATION OF LOGMAKING. THE FOLLOWING SIMULATION RUNS WITH THE MODEL ARE REPORTED: (1) VARYING THE PRODUCTION RATE, (2) CHANGING PRODUCTION POLICIES, (3) VARYING THE AMOUNT OF DEFECTIVE MATERIAL, AND (4) COMPARING PAYMENT SCHEMES.
45. CESARIO, F. J. 1969. OPERATIONS RESEARCH IN OUTDOOR RECREATION. J. LEISURE RES. 1(1):33-51. OPERATIONS RESEARCH METHODS ARE NEEDED FOR PREDICTING TRAVEL FLOW FROM POPULATION CENTERS TO

RECREATION SITES AND ESTIMATING PRIMARY ECONOMIC
BENEFITS OF OUTDOOR RECREATION.

46. CHAPPELLE, D. E. 1963. LINEAR PROGRAMMING AND FARM FORESTRY. J. FOREST. 61(1):56-57. THE AUTHOR CRITICIZES THE TWO SHORTCOMINGS MENTIONED IN STOLTENBERG'S ARTICLE (1962): (1) THE GOAL USUALLY ASSUMED WHEN USING LINEAR PROGRAMMING SELDOM IS THE TRUE GOAL OF FARMERS; AND (2) THE OPTIMAL SOLUTION IN FARM PLANNING MUST BE STABLE, BUT LINEAR PROGRAMMING SOLUTIONS ARE LIKELY TO BE UNSTABLE.
47. CHAPPELLE, D. E. 1966. ECONOMIC MODEL BUILDING AND COMPUTERS IN FORESTRY RESEARCH. J. FOREST. 64(5):329-333. A CLASSIFICATION OF MODELS, AND THE STEPS IN THE MODEL-BUILDING PROCESS. TESTING THE ADEQUACY OF MODELS IS ALSO DISCUSSED FOR THE VARIOUS TYPES. THE ROLE OF DATA PROCESSING EQUIPMENT AT EACH STAGE IS POINTED OUT.
48. CHARNES, A., AND W. W. COOPER. 1961. MANAGEMENT MODELS AND INDUSTRIAL APPLICATIONS OF LINEAR PROGRAMMING. VOL. 2, 393 PP. NEW YORK: JOHN WILEY & SONS, INC. CONTENTS: THE MODIFIED SIMPLEX AND DUAL METHODS AND THE REVISED SIMPLEX CODE FOR ELECTRONIC CALCULATORS, TRANSPORTATION-TYPE MODELS, DYADIC MODELS AND SUBDUAL METHODS, THE DOUBLE-REVERSE METHOD, NETWORKS AND MODELS OF INCIDENCE TYPE, AND GAME THEORY.
49. CHARNES, A., W. W. COOPER, AND A. HENDERSON. 1953. AN INTRODUCTION TO LINEAR PROGRAMMING. NEW YORK: JOHN WILEY & SONS, INC. THIS WORK IS AN ECONOMIC INTRODUCTION TO LINEAR PROGRAMMING, AND GIVES APPLICATIONS, STRAIGHTFORWARD PROGRAMMING CALCULATIONS, AND SOME OF THE MORE DIFFICULT PROBLEMS. LINEAR PROGRAMMING IS DEFINED AS A SCIENCE CONCERNED WITH THE PROBLEM OF PLANNING A COMPLEX OF INTERDEPENDENT ACTIVITIES IN THE BEST POSSIBLE FASHION. A SYSTEMATIC INTRODUCTION TO THE GENERAL THEORY AND SPECIAL ASPECTS OF THE SUBJECT ARE PRESENTED. A BIBLIOGRAPHY IS INCLUDED.
50. CHERNOFF, H., AND L. E. MOSES. 1959. ELEMENTARY DECISION THEORY. 364 PP. NEW YORK: JOHN WILEY & SONS, INC. CHAPTERS ON: DATA PROCESSING, INTRODUCTION TO PROBABILITY AND RANDOM VARIABLES, UTILITY AND DESCRIPTIVE STATISTICS, UNCERTAINTY DUE TO IGNORANCE OF THE STATE OF NATURE, THE COMPUTATION OF BAYES STRATEGIES, INTRODUCTION TO

CLASSICAL STATISTICS, MODELS, TESTING HYPOTHESIS,
AND ESTIMATION OF CONFIDENCE INTERVALS.

51. CHOW, V. T., AND D. D. MEREDITH. 1969. WATER
RESOURCES SYSTEMS ANALYSIS. URBANA DEPT. OF
CIVIL ENG., UNIV. OF ILL. HYDR. ENG. SERIES
19,20,21, & 22, 295 PP. CONTENTS: PART 1,
ANNOTATED BIBLIOGRAPHY ON STOCHASTIC PROCESSES,
PART 2. ANNOTATED BIBLIOGRAPHY ON PROGRAMMING
TECHNIQUES. PART 3. REVIEW OF STOCHASTIC
PROCESSES. PART 4. REVIEW OF PROGRAMMING
TECHNIQUES.
52. CHRISTIANSEN, N. B. 1966. CAPITAL BUDGETING UNDER
CONDITIONS OF UNCERTAINTY. PH. D. DISS. STATE
UNIV., N.Y. COLL. FORESTRY, SYRACUSE. A METHOD
IS PROPOSED WHICH TAKES INTO ACCOUNT THE THEORY OF
DECISION MAKING UNDER CONDITIONS OF UNCERTAINTY
AND THE ACTUAL PRACTICES OF 32 FIRMS IN THE PULP
AND PAPER INDUSTRY. THE METHOD IS TESTED BY
APPLYING IT TO TWO INVESTMENT PROJECTS IN A PULP
AND PAPER FIRM. THE RESULTS OF THE TEST INDICATE
THE METHOD IS WORKABLE ALTHOUGH IT REQUIRES SOME
UNDERSTANDING OF PROBABILITY THEORY ON THE PART OF
COMPANY PERSONNEL.
53. CHRISTIANSEN, N. B. 1968. FOREST RESOURCE
MANAGEMENT AS A SYSTEM. J. FOREST.
66(10):778-781. SYSTEMS ANALYSIS IDENTIFIES
INFLUENTIAL ELEMENTS IN A PROCESS, DESCRIBES THEIR
INTERACTIONS, AND RECOGNIZES THEIR CONTEXT. A
SYSTEMS APPROACH HAS MANY USES IN FORESTRY,
NOTABLY TO PREDICT OUTCOMES AND THUS GUIDE
DECISIONS.
54. CHRISTOPHER, J. F., AND S. GUTTENBERG. 1967. TIMBER
CONVERSION FACTORS AND ECONOMIC BREAK-EVEN POINTS.
AMER. PULPWOOD ASSOC., SOUTHWEST. TECH. DIV. MTG.
AT BATON ROUGE, LA. 14 PP. WHEN CHOICES ARE
NUMEROUS AND INTERRELATED, AS THEY ARE FOR THE
PULP INDUSTRY IN DEALING WITH CHIP MILLS, PLYWOOD
PLANTS, OR MODERN SAWMILLS, THE BREAK-EVEN POINTS
AMONG CHIPS AND PULPWOOD AND ALTERNATIVE PRODUCTS
ARE FAR FROM OBVIOUS. LINEAR PROGRAMMING STUDIES
OF LUMBER AND PLYWOOD PRODUCTION SHOW THAT IT PAYS
TO PULP CLASSES OF LOGS AS LARGE AS 16 INCHES IN
SCALING DIAMETER AND GRADE 2.
55. CHURCHMAN, C. W., R. ACKOFF, AND E. L. ARNOFF. 1957.
INTRODUCTION TO OPERATIONS RESEARCH. 645 PP.,
ILLUS. NEW YORK: JOHN WILEY & SONS, INC. A
GENERAL INTRODUCTION TO METHODS CONCERNING
INVENTORIES, LINEAR PROGRAMMING, WAITING LINE,

REPLACEMENT, AND COMPETITIVE SITUATIONS IS PROVIDED. CASE EXAMPLES ARE USED, AND THE EMPHASIS THROUGHOUT IS ON THE APPLICATION OF OPERATIONS RESEARCH TO INDUSTRIAL PROBLEMS.

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111. FASICK, C. A., AND G. R. SAMPSON. 1966. APPLYING LINEAR PROGRAMMING IN FOREST INDUSTRY. USDA FOREST SERV., SOUTH. FOREST EXP. STA., RES. PAP. NO. 50-21, 12 PP. NEW ORLEANS, LA. THIS PAPER BRIEFLY SHOWS HOW LP CAN BE APPLIED TO PLYWOOD PRODUCTION AT A PINE STUD MILL, AND LUMBER MANUFACTURE; AND INCLUDES INSTRUCTIONS ON PREPARING CARDS FOR INPUT DATA AND INTERPRETING OUTPUT FOR USE WITH THE USDA LP/90 COMPUTER PROGRAM (DAY 1964).
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HARVESTING SYSTEMS. M.S. THESIS, UNIV. MAINE,
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BALANCING PROBLEMS IN FACTORY PRODUCTION COULD BE
APPLIED TO THE REDUCTION OF CERTAIN IMBALANCES IN
PULPWOOD HARVESTING SYSTEMS. A MATHEMATICAL MODEL
WAS CONSTRUCTED FOR DESIGNING A HARVESTING SYSTEM
IN WHICH MEN AND EQUIPMENT ARE SO UTILIZED THAT
TIME AND MONETARY LOSSES DUE TO SYSTEM IMBALANCE
ARE MINIMIZED.

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INCREMENT.) SVERIGES SKOGSV FORB. TIDSKR.
66(8):715-730. (SWEDISH WITH SUMMARIES IN SWEDISH,
ENGLISH.) SIMULATION RESULTS SUGGEST THAT THERE
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(OF THINNING SCHEDULES AND ROTATION) OR AT MOST
ONLY A FEW; AND IT IS LARGELY INDEPENDENT OF PRICE
LEVEL, PRICE RELATIONS FOR DIFFERENT DIMENSIONS,
AND INTEREST RATES (> 3 - 4 PERCENT).
116. FURRESTER, J. W. 1961. INDUSTRIAL DYNAMICS. 464
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STRUCTURE OF A DYNAMIC SYSTEM MODEL, SYSTEMS OF
EQUATIONS, SYMBOLS FOR FLOW DIAGRAMS, REPRESENTING
DELAYS, POLICIES AND DECISIONS, AGGREGATION OF
VARIABLES, EXOGENOUS VARIABLES, JUDGING MODEL
VALIDITY, AND EXAMPLES OF DYNAMIC SYSTEM MODELS.
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COMPUTER MODEL IS USED TO DETERMINE THE EFFECTS OF
DISTANCE TO MARKETS, CUBIC FEET, WEIGHT OF THE
TREE, AND CHANGES IN PRICES ON THE ALLOCATION OF
LOGS TO AN ASSORTMENT OF PRODUCTS.
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FORESTRY OPERATION. FOREST MANAGE. CONTROL CONF.
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ENTERPRISES.) SCHWEIZ. Z. FORSTW.
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121. GABRIEL, W. J. 1970. AN APPROACH TO PROBLEM SOLVING. APPL. FOREST. RES. INST., MISC. REP. 3, 11 PP. STATE UNIV. N. Y., COLL. FOREST., SYRACUSE. THE APPLICATION OF OPERATION RESEARCH, ONE OF THE MOST COMPREHENSIVE APPROACHES TO PROBLEM SOLVING, IS AVAILABLE TO THE FOREST PRODUCTS INDUSTRY.
122. GAMACHE, A. E. 1969. DEVELOPMENT OF A METHOD FOR DETERMINING THE OPTIMUM LEVEL OF FOREST FIRE SUPPRESSION MANPOWER ON A SEASONAL BASIS. PH.D. DISS., UNIV. WASHINGTON. SIMULATION OF SEASONAL FOREST FIRE OCCURRENCE AND SUPPRESSION ACTIVITY WAS USED TO DETERMINE OPTIMUM SEASONAL FOREST FIRE SUPPRESSION MANPOWER. THE SIMULATION WAS USED TO GENERATE THE DATA NECESSARY FOR THE IMPLEMENTATION OF A COST-PLUS-LOSS MODEL AND TO DETERMINE THE SEASONAL MANPOWER LEVEL THAT WOULD MINIMIZE COST-PLUS-LOSS. A HYPOTHETICAL SITUATION AND ACTUAL DATA FROM THE STATE OF WASHINGTON WERE USED TO TEST THE PROCEDURE.
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CRITERIA TO A STUDY OF THE WOOD-BASED SECTOR OF
THE TRINIDAD ECONOMY.

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127. GATEJ, P. 1968. (A MATHEMATICAL MODEL FOR DETERMINING ALLOWABLE CUT IN A REGULAR HIGH FOREST.) INST. POLIT. BRASOV BULL. (SER. B, ECON. FOREST.) 10:193-197. (RUMANIAN, WITH SUMMARIES IN ENGLISH, GERMAN, RUSSIAN.) A DISCUSSION OF THE FEASIBILITY OF USING MATHEMATICAL PROGRAMMING IN FOREST MANAGEMENT, AND A PROPOSED MATHEMATICAL MODEL FOR DETERMINING ALLOWABLE CUT IN A FOREST OF NORMAL AGE STRUCTURE.
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129. GOULD, E. M., JR. 1967. SIMULATION AND FORESTRY. INT. UNION FOREST. RES. ORGAN. CONGR. 14 PAP. VOL. 6:96-104. MUNICH. A COMPUTERIZED MODEL OF THE FOREST IS DISCUSSED.
130. GOULD, E. M., JR., AND W. G. O'REGAN. 1965. SIMULATION - A STEP TOWARD BETTER FOREST PLANNING. HARVARD FOREST PAP. 13, 86 PP. THE READER IS INTRODUCED TO THE USEFULNESS OF MODELS IN PLANNING, ESPECIALLY FOR COMPARING THE PROBABLE OUTCOME OF FOREST MANAGEMENT ALTERNATIVES. A SAMPLE PROBLEM OF A SIMPLE FOREST OPERATING UNIT IS PRESENTED TO AID THOSE INTERESTED IN THE

TECHNIQUE OF SUBMITTING A PROBLEM TO THE COMPUTER.

131. GREVATT, J. G., AND P. A. WARDLE. 1967. TWO MATHEMATICAL MODELS TO AID IN NURSERY PRACTICE. INT. UNION FOREST. RES. ORGAN. CONGR. 14 PROC. PT. VI, SECT. 25:361-370. MUNICH A SIMULATION MODEL, DEVELOPED BY THE FORESTRY COMMISSION IN BRITAIN, WAS DESIGNED TO INDICATE PROGRAMS OF SOWING, TRANSPLANTING, AND STORAGE TO YIELD THE REQUIRED PLANTING STOCK AT LEAST COST. A MODEL WAS ALSO DEVELOPED FOR CALCULATING THE ALLOCATION OF STOCK TO NURSERIES IN RELATION TO SUPPLY, DEMAND, AND TRANSPORT COSTS.
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134. GUTTENBERG, S., AND C. FASICK. 1968. ECONOMICS OF PLYWOOD PRODUCTION IN THE SOUTHERN PINE REGION. FOREST PROD. J. 18(5):43-47. LINEAR PROGRAMMING MODELS FOR ANALYZING PLYWOOD PRODUCTION POSSIBILITIES ARE DEVELOPED FOR A COMPLETE LINE OF SOFTWOOD PLYWOOD. THE OBJECTIVE FUNCTION IS TO MAXIMIZE NET REVENUE OF PLYWOOD PRODUCTION BASED ON: PRICES FOR VENEERS, CORES AND CHIPS; YIELDS OF VENEER, CORES, AND CHIPS; COSTS FOR LOGS; AND LOG VOLUME BY DIAMETER CLASSES.
135. HADLEY, G. 1962. LINEAR PROGRAMMING. 520 PP. READING, MASS.: ADDISON-WESLEY PUBLISHING CO. CHAPTERS ON: MATHEMATICAL BACKGROUND, THEORY OF THE SIMPLEX METHOD, COMPUTATIONAL ASPECTS OF THE SIMPLEX METHOD, THE DEGENERACY PROBLEM, DUALITY, TRANSPORTATION PROBLEMS, NETWORK FLOWS,

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ECONOMIC THEORY.

136. HADLEY, G. 1964. NONLINEAR AND DYNAMIC PROGRAMMING. 484 PP. READING, MASS.: ADDISON-WESLEY PUBLISHING CO. CHAPTERS ON: MATHEMATICAL BACKGROUND, CLASSICAL OPTIMIZATION METHODS AND PROPERTIES OF CONVEX FUNCTIONS, APPROXIMATE METHODS FOR SOLVING PROBLEMS INVOLVING SEPARABLE FUNCTIONS, STOCHASTIC PROGRAMMING, KUHN-TUCKER THEORY, QUADRATIC PROGRAMMING, INTEGER LINEAR PROGRAMMING, GRADIENT METHODS, AND DYNAMIC PROGRAMMING.
137. HADLEY, G., AND T. M. WHITIN. 1963. ANALYSIS OF INVENTORY SYSTEMS. 452 PP. ENGLEWOOD CLIFFS, N.J.: PRENTICE-HALL, INC. THIS BOOK ALSO DISCUSSES ELEMENTS OF STATISTICS, MARKOV PROCESSES, AND EVEN DYNAMIC PROGRAMMING AND ITS USES IN INVENTORY MODELS.
138. HALL, O. F. 1960. FOREST VALUATION USING INVENTORY DATA. FOREST MANAGE. CONTR. CONF. PROC. #199-207. PURDUE UNIV., LAFAYETTE, IND. THREE METHODS OF VALUATION OF FORESTED PROPERTY ARE DISCUSSED: VALUE FOR IMMEDIATE LIQUIDATION, MARKET VALUE TO ANY OWNER FOR CONTINUOUS PRODUCTION, AND STRATEGIC VALUE TO A PARTICULAR OWNER. AN ILLUSTRATION IS GIVEN USING LINEAR PROGRAMMING TECHNIQUES FOR FINDING THE OPTIMUM METHOD OF OPERATION FOR A SMALL PULPMILL WITH ALTERNATIVE SOURCES OF WOOD (VIZ. LAND PURCHASE, LAND ALREADY OWNED, FARM WOODLANDS, RAIL TRANSPORT FROM A DISTANCE).
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140. HAMILTON, H. R. 1963. RESEARCH TAKES AIM AT HARVESTING AND WOODFLOW PROBLEMS IN THE SOUTH. PULP AND PAPER MAG. CAN. 37(1):51-53. BATTELLE

MEMORIAL INSTITUTE, UNDER SPONSORSHIP OF THE AMERICAN PULPWOOD ASSOCIATION, IS CONDUCTING RESEARCH ON PULPWOOD PROBLEMS IN THE SOUTHEAST. THE PURPOSE OF THE PROJECT (WHICH INVOLVES A DYNAMIC MATHEMATICAL MODEL), THE SOCIAL AND PHYSICAL SCIENCES CONTRIBUTING TO IT, AND THE PROBLEMS IT FACES - - SUCH AS SMALL WOODLANDS, MAN-HOUR, AND MILL-SUPPLIER RELATIONSHIPS - - ARE DISCUSSED.

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142. HAMILTON, H. R. 1964. ATTACKING A PAPER INDUSTRY PROBLEM BY SIMULATION. TAPPI 47(11):678-683. A DYNAMIC MATHEMATICAL MODEL OF WOOD PROCUREMENT IN THE SOUTHEASTERN UNITED STATES WAS CONSTRUCTED USING THE INDUSTRIAL DYNAMICS TECHNIQUE. SIMULATION WITH THE MODEL POINTS TO THE DESIRABILITY OF CHANGING THE WOOD-HAULING PORTION OF THE PROCUREMENT SYSTEM FROM PRODUCER-HAULING TO CONTRACT-HAULING.
143. HAMILTON, H. R. 1966. HIGHLIGHTS OF THE BATTELLE STUDY OF SOUTHEASTERN PULPWOOD HARVESTING. AMERICAN PULPWOOD ASSOC. TECH. REL. 66-R-10, 25 PP. NEW YORK. PRIMARILY A GENERAL DISCUSSION OF ALL ASPECTS OF THE STUDY. HOWEVER, ON PAGES 22 TO 25, THE COMPUTER SIMULATION MODEL IS DISCUSSED, INCLUDING THE RESULTS THAT WERE OBTAINED WHEN LABOR SHORTAGES AND WEATHER WERE VARIED IN THE MODEL.
144. HAMILTON, H. R., AND A. L. PUGH, III. 1963. PROGRESS REPORT TO AMERICAN PULPWOOD ASSOCIATION ON A DYNAMIC, MATHEMATICAL MODEL OF PULPWOOD PRODUCTION IN THE SOUTHEAST. BATTELLE MEMORIAL INST., 32 PP. PLUS APPENDICES. CONTRACT HAULING OFFERS A MEANS FOR THE PRODUCER TO EFFECTIVELY ALTER CREW SIZE WITHOUT MAKING LONG-TERM FINANCIAL COMMITMENTS. PRODUCERS SHOULD ALSO EXAMINE FINANCIAL AND OPERATIONAL ALTERNATIVES TO THE FLUCTUATING SEASONAL INVENTORY POLICIES NOW COMMON IN THE SOUTHEAST.

145. HAMMERSLEY, J. M., AND D. C. HANDSCOMB. 1964. MONTE CARLO METHODS. 178 PP. LONDON: METHUEN AND CO., LTD. A SURVEY OF MONTE CARLO TECHNIQUES.
146. HAYNES, R. W. 1968. AN APPROACH TO CONSIDERING UNCERTAINTY IN DEVELOPING LONG-TERM, LEAST-COST WOOD PROCUREMENT POLICIES. M.S. THESIS, VA. POLYTECH. INST., BLACKSBURG. UNCERTAINTY IS INTRODUCED INTO A WOOD PROCUREMENT PROBLEM THROUGH THE USE OF A PARTIAL STOCHASTIC LINEAR PROGRAM.
147. HETRICK, J. C. 1968. ROLE OF THE COMPUTER. FIFTH ANN. FOREST INDUS. MARKET. CONF. PROC. (THE DYNAMICS OF DISTRIBUTION):31-51. UNIV. OREG., FOREST INDUS. MANAGE. CENTER, PORTLAND. A COMPUTERIZED MODEL CAN BE DEVELOPED TO REPRESENT THE DISTRIBUTION SYSTEM OF A COMPANY. THE MODEL TELLS MANAGEMENT THE VARIOUS OPTIONS IT HAS IN DECIDING OPTIMUM INVENTORY SIZE AND NUMBER OF WAREHOUSES IN RELATION TO VOLUME AND PATTERN OF SALES DEMAND.
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150. HUFLE, H. H. 1967. BEST MECHANICAL ORGANIZATION IN THE PRODUCTION OF SOFTWOOD PRODUCTS THROUGH THE USE OF LINEAR PROGRAMMING. AUS. DEM INSTITUTE FUER FORSTBENUTZUNG UND FORSTLICHE, ARBEITSWISSENSCHAFT DER UNIVERSITAT FREIBURG, 236 PP. (IN GERMAN, SUMMARY IN ENGLISH.) PRINCIPLES OF SYSTEMS ANALYSIS EXEMPLIFIED BY THE FOREST FIRM CONVERTING SMALL-DIAMETER WOOD TO SALABLE PRODUCTS. STEPS IN MODEL BUILDING, CONCEPTS OF

LINEAR PROGRAMMING.

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153. HOLLEY, D. L. 1969. POTENTIAL GROWTH OF THE SOUTHERN PINE PLYWOOD INDUSTRY. USDA FOREST SERV., SOUTH, FOREST EXP. STA., RES. PAP. NO. SO-41, 22 PP, NEW ORLEANS, LA. THE OPTIMUM DISTRIBUTION OF PLYWOOD PRODUCTION IN THE UNITED STATES WAS ESTIMATED BY MEANS OF LINEAR PROGRAMMING. THE RESULTS INDICATE THAT IN 1975, THE SOUTH WILL BE SUPPLYING 30 PERCENT OF THE TOTAL PROJECTED NATIONAL CONSUMPTION OF SOFTWOOD PLYWOOD AND MAINTAINING ITS OUTPUT OF SAWN TIMBERS.
154. HOLLEY, D. L. 1970. SOFTWOOD PLYWOOD AND LUMBER INDUSTRIES: A REGIONAL PROGRAMMING ANALYSIS. LAND ECON., 46(2):127-137. AN ANALYSIS OF THE CURRENT STATE OF LOCATIONAL INSTABILITY IN THE PLYWOOD AND LUMBER INDUSTRIES USING A SPATIAL EQUILIBRIUM TRANSPORTATION MODEL. USING 1965 PRODUCTION DATA, THE ANALYSIS MEASURES HOW FAR THE LOCATION OF THE TWO INDUSTRIES HAS DRIFTED FROM THE PERFECTLY COMPETITIVE IDEAL.
155. HUOL, J. N. 1965. A DYNAMIC PROGRAMMING -- MARKOV CHAIN APPROACH TO FOREST PRODUCTION CONTROL. PH.D. DISS., PURDUE UNIV., LAFAYETTE, IND. A PRESENTATION OF A MATHEMATICAL CONTROL METHOD THAT CONSIDERS THE EFFECTS OF INCOMPLETELY CONTROLLED

INFLUENCES ON RENEWABLE NATURAL RESOURCES. THIS APPROACH COMBINES DYNAMIC PROGRAMMING, A GENERAL MATHEMATICAL SOLUTION METHOD, WITH MARKOV CHAINS.

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157. HOOL, J. N. 1966. A DYNAMIC PROGRAMMING - PROBABILISTIC APPROACH TO FOREST PRODUCTION CONTROL. SOC. AMER. FOREST. PROC. 1965:191-193. A BRIEF EXPOSITION OF A PROBABILISTIC DECISION-MAKING METHOD THAT CAN BE USED IN PRESCRIBING FOREST YIELD-REGULATION OPERATIONS SUCH AS THINNING AND HARVESTING OVER ANY LENGTH OF TIME WHILE ALLOWING FOR RANDOM DEVELOPMENT IN THE FOREST SYSTEM. THE METHOD COMBINES STOCHASTIC AND OPTIMIZATION TECHNIQUES FOR PRESCRIBING THE OPERATIONS.
158. HOOL, J. N. 1968. AN UNIVARIATE ALLOCATION ALGORITHM FOR USE IN FORESTRY PROBLEMS. J. FOREST. 66(6):492-493. A DYNAMIC PROGRAMMING ALGORITHM FOR THE OPTIMIZATION OF UNIVARIATE ALLOCATION PROBLEMS IS ILLUSTRATED BY A HYPOTHETICAL MAXIMIZATION PROBLEM. THE ALGORITHM REQUIRES THE EVALUATION OF ONLY A FRACTION OF THE TOTAL NUMBER OF POSSIBLE ALLOCATION COMBINATIONS.
159. HOWARD, R. A. 1965. A MODEL FOR TREE GROWTH. M.S. THESIS, UNIV. CALIF., BERKELEY. THE PRESENTATION OF A MODEL THAT GENERATES ANNUAL VALUES FOR HEIGHT AND DIAMETER GROWTH, ANNUAL RING SUMMERWOOD PERCENT, AND SPECIFIC GRAVITY AT BREAST HEIGHT FOR AN INDIVIDUAL TREE. OPERATING RULES TO DESCRIBE THE EFFECT OF SITE QUALITY, STAND DENSITY, AND CLIMATIC FACTORS ON THE DESIRED OUTPUTS WERE DEVISED FROM PUBLISHED RESEARCH FINDINGS. THE MODEL IS PROGRAMMED FOR COMPUTER SIMULATION ANALYSIS OF A 40-YEAR PERIOD OF GROWTH.
160. HOWELL, R. A. 1963. LINEAR PROGRAMMING FOR THE SELECTION OF AN OPTIMUM FOREST HARVESTING SCHEDULE. M.S. THESIS, UNIV. FLA. GAINESVILLE. THE TRANSPORTATION METHOD OF LINEAR PROGRAMMING WAS USED TO DETERMINE A BEST HARVESTING SEQUENCE FOR THREE DIFFERENT MANAGEMENT OBJECTIVES (AREA

CONTROL, FUTURE AREA CONTROL, AND VOLUME CONTROL). IN EVALUATING THE EFFECTIVENESS OF THE PROGRAM, THE POOREST POSSIBLE HARVESTING SCHEDULE WAS COMPUTED FOR EACH TYPE OF MANAGEMENT. IN EACH CASE, IT WAS FOUND THAT THE LINEAR PROGRAMMING SOLUTION COULD HAVE PROVIDED A SUBSTANTIAL INCREASE IN THE PRESENT VALUE OF PROPERTY.

161. HUGHES, J. M. 1970. FORESTRY IN ITASCA COUNTY'S ECONOMY - - AN INPUT-OUTPUT ANALYSIS. UNIV. MN., AGR. EXP. STA., MISC. RPT. 95, FOREST. SERIES 4, 98 PP. MINNEAPOLIS. A 39 BY 39 SECTOR INPUT-OUTPUT MODEL OF THE ITASCA COUNTY (MINN.) ECONOMY FOR 1966 WAS CONSTRUCTED, AND MULTIPLIERS WERE DEVELOPED FOR ESTIMATING SHORT-RUN IMPACTS OF POTENTIAL CHANGES. FORESTRY-RELATED SECTORS, INCLUDING TIMBER PRODUCTION, SAWMILLING, AND TIMBER OPERATORS WERE GIVEN MAJOR ATTENTION, SINCE THESE ACTIVITIES HAVE EXPANSION POSSIBILITIES IN THE COUNTY AND PERHAPS REPRESENT SOME OPPORTUNITIES FOR FUTURE DEVELOPMENT. SEVERAL EXAMPLES OF POSSIBLE CHANGES ARE ALSO PRESENTED.
162. HUGHES, J. M. 1970. SMALL AREA INPUT-OUTPUT STUDIES OF FORESTRY-RELATED ACTIVITIES IN MINNESOTA. PAPER PRESENTED AT MINN. CHAMBER OF COMM. INPUT-OUTPUT CONF., 10 PP. MINNEAPOLIS. THE HIGHLIGHTS OF THE ITASCA COUNTY INPUT-OUTPUT STUDY ARE DISCUSSED (SEE PREVIOUS CITATION) AND BRIEF DESCRIPTIONS OF TWO ADDITIONAL INPUT-OUTPUT STUDIES ARE PRESENTED.
163. HURWICZ, L. 1955. GAME THEORY AND DECISIONS. SCI. AMER. 192(2):78-83. A Nontechnical EXPLANATION OF GAME THEORY ILLUSTRATED BY SIMPLE MATHEMATICAL PROBLEMS. THE THEORY PROVIDES A WAY IN WHICH PROBLEMS INVOLVING UNCERTAINTY CAN BE TREATED SCIENTIFICALLY BY MEANS OF THE MATHEMATICS OF PROBABILITY. THERE IS A SHORT DISCUSSION OF THE VARIOUS STRATEGIES AN INDIVIDUAL CAN EMPLOY TO MAXIMIZE HIS GAIN AND MINIMIZE HIS LOSS.
164. INSTITUTE OF FOREST ECONOMICS. 1968. ANNUAL REPORT NO. 7. AGR. COLL. NORWAY, VOLLEREKK, NORWAY. 72 PP. A DISCUSSION OF THE USE OF OPERATIONS RESEARCH IN FORESTRY, ESPECIALLY DYNAMIC PROGRAMMING, IS INCLUDED.
165. JABLOKOV, A. N. 1965. (THE USE OF ELECTRONIC COMPUTERS FOR CALCULATING MAXIMUM OUTURNS OF SAWN TIMBER.) LESN. Z. ARHANGEL'SK 8(6):152-159. (IN RUSSIAN.) A THEORETICAL STUDY IN WHICH THE AUTHOR ANALYZES CONVENTIONAL MATHEMATICAL MODELS

- USED IN SAWMILLING FOR CALCULATING FRAME-SAW SCHEDULES THAT WILL GIVE OPTIMUM BOARD OUTTURN FROM GIVEN LOG DIMENSIONS IN ORDER TO DERIVE AN ALGORITHM FOR PROGRAMMING ANALOG AND DIGITAL COMPUTERS TO CARRY OUT THESE CALCULATIONS.
166. JACK, W. H. 1967. A SIMPLE EXAMPLE OF MANAGEMENT PLANNING. N. IRE. FOREST, 8(2):8-13. LINEAR PROGRAMMING IS USED IN A SIMPLE EXAMPLE TO DETERMINE THE BEST MARKET FOR A MIX OF PRODUCTS AND FORESTS.
167. JACKSON, N. D. 1958. A METHOD OF DETERMINING THE OPTIMUM WAYS OF CONVERTING SAWLOGS INTO LUMBER. M.S. THESIS, N.C. STATE COLL., RALEIGH. TWO DIFFERENT TYPES OF PROBLEMS, PROFIT MAXIMIZATION AND PRODUCTION MAXIMIZATION, ARE EXAMINED TO ILLUSTRATE HOW LINEAR PROGRAMMING CAN BE APPLIED TO THE SAWMILL INDUSTRY. THE FIRST PROBLEM DEMONSTRATES THAT LINEAR PROGRAMMING CAN BE EFFECTIVELY USED TO COMPUTE OPTIMUM SAWING METHODS TO PRODUCE LUMBER THAT WILL RETURN MAXIMUM PROFITS. THE SECOND PROBLEM DEALS WITH ALLOCATION OF MACHINE AND LABOR TIME SO THAT DAILY PRODUCTION OF THE MILL IS MAXIMIZED.
168. JACKSON, N. D., AND G. W. SMITH. 1961. LINEAR PROGRAMMING IN LUMBER PRODUCTION. FOREST PROD. J. 11(6):272-274. A TECHNIQUE FOR DETERMINING THE OPTIMUM COMBINATION OF LUMBER SIZES TO BE CUT FROM EACH LOG IS DESCRIBED, TAKING INTO ACCOUNT AVAILABLE LOG SIZES, SALES RESTRICTIONS IMPOSED BY THE PURCHASER, CONVERSION COSTS, AND PRICES FOR THE DIFFERENT DIMENSIONS YIELDED BY EACH LOG; AND ILLUSTRATED BY DATA FROM ELEVEN NORTH CAROLINA MILLS.
169. JEFFERS, J. N. R. 1964. MATHEMATICAL MODELS IN FORESTRY RESEARCH. COMMONWEALTH FOREST REV. 43(2):159-168. THE ADVANTAGES OF MATHEMATICAL MODELS FOR SIMULATING PRACTICAL SITUATIONS FOR PURPOSES OF DESCRIPTION, PREDICTION, AND DECISION-MAKING ARE PRESENTED. THE MAINTENANCE OF FOREST SEED STOCKS, THE PRODUCTION AND ALLOCATION OF NURSERY STOCK, THE RECRUITMENT OF INDUSTRIAL LABOR, THE COST OF ESTABLISHMENT OF PLANTATIONS, THE ALLOCATION OF SUPERVISORY STAFF, AND PRODUCTION PLANNING PROVIDE EXAMPLES OF THEIR USE.
170. JONES, T. A. 1960. LINEAR PROGRAMMING APPLIED TO A WOOD SUPPLY PROBLEM. FOREST MANAGE. CONTR. CONF. PROC., PURDUE UNIV., LAFAYETTE, IND. A PRESENTATION OF A METHOD FOR MINIMIZING COSTS IN A

SUPPLY SYSTEM AS IT ACTUALLY EXISTS IN THE PULP AND PAPER INDUSTRY. WOOD OF DIFFERENT SPECIES, BARKED AND DEBARKED, IS ALLOCATED TO SEVERAL PULPMILLS OVER RAIL OR BY TRUCK.

171. KAISER, H. F., JR. 1965. CHRISTMAS TREES, DECISION TREES, AND MODERN CAPITAL MANAGEMENT. M.S. THESIS, IOWA STATE UNIV., IOWA CITY. A QUANTITATIVE MODEL BASED ON THE DECISION-TREE CONCEPT IS PRESENTED TO SERVE AS AN AID TO AN INVESTOR INTERESTED IN THE EVALUATION OF SEQUENTIAL DECISIONS INVOLVING CHRISTMAS TREE PRODUCTION. THE MODEL DEMONSTRATES THE INTERACTION BETWEEN PRESENT DECISIONS, CONDITIONAL PROBABILITIES, AND POSSIBLE FUTURE DECISIONS.
172. KAISER, H. F., JR. 1968. INTERINDUSTRY MODEL OF THE U.S. FOREST PRODUCTS ECONOMY. FOREST PROD. J. 18(11):15-18. AN INPUT-OUTPUT MODEL IS DEVELOPED TO SHOW THE FLOW OF GOODS THROUGH THE FOREST PRODUCTS ECONOMY. DATA FROM THE 1963 CENSUS OF MANUFACTURERS ARE USED TO ANALYZE EACH FOREST INDUSTRY'S CONTRIBUTION TO THE ECONOMY. DIRECT AND INDIRECT EFFECTS OF AN INCREASE IN FINAL DEMAND FROM EACH INDUSTRIAL SECTOR ARE DETERMINED.
173. KAISER, H. F., JR. 1969. INPUT-OUTPUT ANALYSIS OF THE SOUTHERN FOREST ECONOMY, 1963. USDA FOREST SERV., SOUTH. FOREST EXP. STA., RES. PAP. SD-43, 18 PP. NEW ORLEANS, LA. AN INPUT-OUTPUT MODEL IS DEVELOPED TO SHOW THE FLOW OF GOODS THROUGH THE SOUTHERN FOREST ECONOMY. ANALYSIS OF UNPUBLISHED DATA FROM THE 1963 CENSUS OF MANUFACTURES INDICATES THAT PRIMARY PROCESSING INDUSTRIES PRODUCED \$5,126 MILLION WORTH OF OUTPUT WHILE PURCHASING STUMPPAGE COSTING \$335 MILLION. SECONDARY PROCESSING INDUSTRIES CONVERTED A PORTION OF THIS OUTPUT INTO PRODUCTS WORTH \$3,365 MILLION. COLLECTIVELY, FOREST-RELATED INDUSTRIES PAID \$2,181 MILLION IN WAGES TO SOUTHERNERS.
174. KASATKIN, M. G. 1966. APPLYING A DETERMINISTIC MODEL TO A DYNAMIC PRODUCTION SCHEDULING SEMINAR ON OPER. RES. IN FOREST PROD. INDUS. PROC.:40-51, IBM CORP., LOS ANGELES, CALIF. AN ALLOCATION MODEL IS USED IN A PRODUCTION-SCHEDULING PROBLEM THAT CONSISTS OF DIRECTING ORDERS OF VARIOUS GRADES AND WEIGHTS OF PAPER TO THE PROPER MACHINE FOR THE MOST EFFICIENT AS WELL AS PROFITABLE SOLUTION.
175. KEMENY, J. G., A. SCHLEIFER, JR., J. L. SNELL, AND G. L. THOMPSON. 1962. FINITE MATHEMATICS WITH

BUSINESS APPLICATIONS. 482 PP. ENGLEWOOD CLIFFS, N.J.: PRENTICE-HALL, INC. CONTENTS: COMPOUND STATEMENTS, SETS AND SUBSETS, PARTITIONS AND COUNTING, PROBABILITY THEORY, VECTORS AND MATRICES, MATHEMATICS OF FINANCE AND ACCOUNTING, LINEAR PROGRAMMING, AND THE THEORY OF GAMES.

176. KENNEDY, J. J., JR. 1966. THE ECONOMIC IMPACT OF OUTDOOR RECREATION ACTIVITIES ON A RURAL AREA ECONOMY: AN INPUT-OUTPUT APPROACH. M.S. THESIS, PENN STATE UNIV., UNIVERSITY PARK. A VARIATION OF THE LEONTIEF INPUT-OUTPUT MODEL DESIGNED AND CONSTRUCTED BY H. B. GAMBLE (1965) WAS APPLIED TO ESTIMATE THE ECONOMIC IMPACT OF OUTDOOR RECREATION EXPENDITURES UPON RURAL AREA ECONOMICS. THE QUANTITATIVE CONCLUSIONS RESULTING FROM INPUT-OUTPUT ANALYSIS MUST BE SUPPLEMENTED WITH QUALITATIVE CONSIDERATIONS OF THE SHORT AND LONG RUN CONSEQUENCES OF SUCH ALTERNATIVES.
177. KIDD, W. E., JR. 1965. A LINEAR PROGRAMMING APPROACH TO EVALUATING FOREST MANAGEMENT ALTERNATIVES. M.S. THESIS, VA. POLYTECH. INST., BLACKSBURG. THE APPROPRIATENESS OF ADAPTING LINEAR PROGRAMMING TO EVALUATION OF TIMBER-HARVESTING ALTERNATIVES IS EXAMINED. USE OF LINEAR PROGRAMMING RATHER THAN ONE OF SEVERAL OTHER ECONOMIC ALLOCATION MODELS IS JUSTIFIED. THE BASIC MODEL DESCRIBES ALTERNATIVE THINNING AND HARVESTING OPPORTUNITIES ON THE SEWARD FOREST AT TRIPPLETT, VIRGINIA, AND THE SOLUTION DESCRIBES A COURSE OF ACTION FOR THE FOREST MANAGER OVER THE NEXT 50 YEARS.
178. KIDD, W. E., JR., F. F. THOMPSON, AND P. H. HOEPNER. 1966. FOREST REGULATION BY LINEAR PROGRAMMING - A CASE STUDY. J. FOREST, 64(9):611-613. THE APPLICATION OF LINEAR PROGRAMMING TO THE REGULATION OF TIMBER HARVESTS FROM A GIVEN FOREST IS SHOWN. THE CONCLUSION IS THAT LP CAN BE USED TO PROVIDE OPTIMUM SOLUTIONS TO FOREST REGULATION PROBLEMS. LP CAN ALSO ENABLE A FOREST MANAGER TO PREDICT THE EFFECT OF A CHANGE IN MANAGERIAL CONSTRAINTS.
179. KILANDER, K. 1966. THE NEW TRENDS OF THINKING IN FOREST MANAGEMENT METHODS. 6TH WORLD FOREST. CONGR., MADRID. 7 PP. (IN ENGLISH, FRENCH, AND SPANISH.) THE GROWTH OF ANALYTICAL METHODS INCLUDES MATHEMATICAL APPROACHES SUCH AS LINEAR AND DYNAMIC PROGRAMMING, THE THEORY OF GAMES, ETC. THE POSSIBILITIES OF USING THESE TECHNIQUES DIRECTLY ON PRACTICAL FOREST-MANAGEMENT PROBLEMS

ARE OFTEN FEWER THAN THEY SEEM AT FIRST.

180. KILKKI, P. J. 1967. ECONOMIC MODELS FOR SCHEDULING TIMBER CUTTING ACTIVITIES. M.S. THESIS, UNIV. CALIF., BERKELEY. PLANNING MODELS BASED ON A SPECIFIED CASH FLOW GOAL OF THE FOREST OWNER ARE DEVELOPED. A SIMULATION MODEL WAS FIRST DEVELOPED, HOWEVER, THIS DID NOT INSURE THAT THE OBJECTIVE FUNCTION WOULD BE MAXIMIZED. THEREFORE A LINEAR PROGRAMMING MODEL FOR PLANNING CUTTING BUDGETS WAS ALSO DEVELOPED. THE SIMULATOR WAS FOUND TO BE SLIGHTLY PREFERABLE TO THE LP MODEL IF COMPUTER PROGRAMS ARE AVAILABLE FOR BOTH.
181. KILKKI, P. J. 1968. (INCOME-ORIENTED CUTTING BUDGET.) ACTA FOREST. FENN. 91, 54 PP. (ENGLISH, WITH SUMMARIES IN ENGLISH, FINNISH.) TWO CUTTING BUDGET MODELS ARE DEVELOPED BY THE APPLICATION OF SIMULATION AND LINEAR PROGRAMMING; THESE ARE APPLICABLE ONLY TO EVEN-AGED PINUS SYLVESTRIS FORESTS ON THREE DIFFERENT SITES, BUT THEY COULD EASILY BE ADAPTED TO OTHER SPECIES AND MANY MORE SITES. THE CUTTING BUDGET MODELS IN THIS STUDY ASSUME THAT THE GOAL OF THE FOREST OWNER LIES IN THE INCOME DERIVED FROM HIS FOREST UNDERTAKING.
182. KILKKI, P. J. 1968. (LINEAR PROGRAMMING IN FOREST PLANNING.) METSATALOUDELLINEN AIKAKAUSLEHT 85(2):42-43, 57. HELSINKI (IN FINNISH WITH SUMMARY IN ENGLISH.) AN EXAMPLE IS DRAWN TO ILLUSTRATE LINEAR PROGRAMMING IN FOREST REGENERATION. A FOREST AREA COMPRISING THREE SITES IS TO BE REGENERATED BY MEANS OF EITHER PLANTING OR NATURAL REGENERATION. THE AIM IS THAT OF MAXIMIZING THE DISCOUNTED NET REVENUES FROM THE REGENERATION AREA. IN ADDITION TO THE REGENERATION AREA, THE LABOR AND THE CAPITAL AVAILABLE FORM THE CONSTRAINTS FOR THE LINEAR PROGRAMMING PROBLEM.
183. KILKKI, P. J., AND U. VAISANEN. 1970. (DETERMINATION OF THE OPTIMUM CUTTING POLICY FOR THE FOREST STAND BY MEANS OF DYNAMIC PROGRAMMING.) ACTA FOREST. FENN. 102, 23 PP. HELSINKI. (IN FINNISH.) DYNAMIC PROGRAMMING IS USED TO DETERMINE THE OPTIMUM CUTTING PROGRAMS FOR EVEN-AGED SCOTCH PINE STANDS IN SOUTHERN FINLAND. THREE LOGGING COST LEVELS, THINNING FROM ABOVE AND BELOW, AND INTEREST RATES FROM 1 TO 5 PERCENT, ARE APPLIED. THE ECONOMIC RESULTS OF BOTH OPTIMUM ROUTES AND DIFFERENT CUTTING PROGRAMS ARE ANALYZED.
184. KINNE, S. B., III. 1966. MAXIMIZING RETURNS OF A

FARM-FOREST ENTERPRISE USING A DYNAMIC LINEAR PROGRAMMING MODEL. M.S. THESIS, PURDUE UNIV., LAFAYETTE, IND. A DYNAMIC LINEAR PROGRAMMING MODEL THAT PERMITS THE CONCURRENT PLANNING OF FARM AND FOREST ACTIVITIES IS DEVELOPED. THIS TECHNIQUE PERMITS THE VARIOUS ACTIVITIES TO COMPETE FOR AVAILABLE LABOR. IT ALSO ALLOWS DIFFERENT GROWTH RATES TO BE CONSIDERED FOR DIFFERENT AREAS OF THE WOODLAND, AND THE GROWTH RESULTING FROM THE WOODLAND ACTIVITIES TO ACCUMULATE FOR HARVEST AT LATER TIMES.

185. KOENIGSBERG, E. 1960. APPLYING LINEAR PROGRAMMING TO THE PLYWOOD INDUSTRY. FOREST PROD. J. 10(9):481-486. LINEAR PROGRAMMING TECHNIQUES PROVIDE MANAGEMENT WITH IMPROVED INFORMATION TO AID IN DECISIONS ON LOG PURCHASES, PEELING OF VENEERS, AND USING THE VENEERS TO PRODUCE A MORE PROFITABLE PRODUCT MIX.
186. KOOPMANS, TJALLING, C., ED. 1951. ACTIVITY ANALYSIS OF PRODUCTION AND ALLOCATION. 404 PP., ILLUS. NEW YORK: JOHN WILEY & SONS, INC. LINEAR PROGRAMMING CONSISTS OF THE DETERMINATION OF NON-NEGATIVE VARIABLES, WHICH OPTIMIZE A LINEAR FORM SUBJECT TO LINEAR CONSTRAINTS. THIS BOOK REPORTS A CONFERENCE ON LINEAR PROGRAMMING HELD IN CHICAGO UNDER THE AUSPICES OF THE COWLES COMMISSION FOR RESEARCH IN ECONOMICS. TWENTY-FIVE RESEARCH PAPERS DEALING WITH LINEAR PROGRAMMING PROPER, AND SUCH RELATED TOPICS AS INTER-INDUSTRY INPUT-OUTPUT MODELS ARE INCLUDED.
187. KORINEK, J. 1966. (THE POSSIBILITIES OF USING THE METHOD OF LINEAR PROGRAMMING IN THE NEW FORESTRY CONTROL SYSTEM.) BRNO, UNIV. AGR. ANNIV. AGR. STUD. SCI. SYMP. 150:64-65. (CZECHOSLOVAKIAN WITH SUMMARIES IN ENGLISH, RUSSIAN, FRENCH, AND GERMAN.) THE SIMPLEX MODEL IS USEFUL IN FINDING THE MOST PROFITABLE ASSORTMENT OF TIMBER TO PRODUCE, IN PLANNING PRODUCTION AND SUPPLY, IN WEIGHING TIMBER-MARKETING POSSIBILITIES, IN FINDING THE OPTIMUM PROCEDURE FOR HANDLING TIMBER AT LUMBER SHIPPING YARDS, AND IN PLANNING THE CAPACITY AND LOCATION OF TIMBER YARDS.
188. KOURTZ, P. H. 1967. FORECASTING FOREST FIRE DANGERS BY COMPUTER. FOREST FIRE RES. INST. INFORM. REP. FF-X-7, 10 PP. OTTAWA, ONT., CAN. A DESCRIPTION OF THE CANADIAN FIRE-DANGER RATING SYSTEM, THE EXISTING FIRE-DANGER FORECASTING PROCEDURE, AND THE PREPARATION OF A COMPUTER PROGRAM AVAILABLE FROM THE FOREST FIRE RESEARCH INSTITUTE, FOR

HANDLING THE FIRE-DANGER FORECASTING WORK OF THE MARITIME PROVINCES.

189. KOURTZ, P. H. 1968. COMPUTERS AND FOREST FIRE DETECTION. FOREST. CHRON. 44(2):22-24. A GENERAL DESCRIPTION OF A COMPUTER SIMULATION PROGRAM FOR FIRE DETECTION BASED ON HISTORICAL DATA. THE ELAPSED TIME A FIRE BURNS BEFORE DETECTION CAN BE USED TO CALCULATE THE AREA BURNED BY EACH FIRE, WHICH IN TURN CAN BE USED TO SELECT THE MOST DESIRABLE DETECTION ALTERNATIVE.
190. KOURTZ, P. H., AND W. G. O'REGAN. 1968. A COST-EFFECTIVENESS ANALYSIS OF SIMULATED FOREST FIRE DETECTION SYSTEMS. HILGARDIA 39(12):341-366. THE MOST EFFECTIVE COMBINATION OF LOOKOUTS AND AIRCRAFT IS FOUND FOR FOREST FIRE DETECTION WITHIN A GIVEN BUDGET.
191. KUDINOV, A. A. 1966. (DETERMINING CRITERIA OF THE PSYCHOLOGICAL LOAD ON THE OPERATORS OF CROSCUTTING UNITS.) LESN. Z. ARHANGEL'ISK 9(1):149-154. (IN RUSSIAN.) AN ANALYSIS BASED ON INFORMATION THEORY SHOWS THAT A MAN OPERATING A LOG CROSCUTTING UNIT HAVING A THROUGHPUT OF 300 CU. M./SHIFT HAS TO HANDLE INFORMATION AT THE RATE OF 4,18 BITS/SEC. THIS IS CLOSE TO OR BEYOND THE LIMIT OF HIS MENTAL POWERS, SO FOR THROUGHPUTS > 300 CU. M./SHIFT, HE WOULD BE INCAPABLE OF SELECTING THE OPTIMUM CROSCUTTING PROGRAM; THEREFORE, AUTOMATIC PROGRAMMING DEVICES ARE NEEDED.
192. LA BASTIDE, J. G. A., AND M. BOL. 1969. (SIMULATION AS A TOOL IN FORESTRY RESEARCH.) FORSTARCHIV 40(1):7-11. (IN GERMAN WITH ENGLISH SUMMARY.) THE METHOD IS CONSIDERED PARTICULARLY SUITABLE FOR COMPLEX PROBLEMS WITH INTERACTING VARIABLES. AN EXAMPLE IS GIVEN OF ITS APPLICATION TO PROBLEMS DEALING WITH THE COST OF SKIDDING TREE-LENGTH THINNINGS FROM STANDS OF DIFFERENT SIZE, DENSITY, VOLUME, ETC. TREATMENT VARIABLES ARE SIZE AND SPACING OF STACKS (IF ANY) AND EXTRACTION METHODS.
193. LAPSAKOV, I. D., AND V. V. UVCHINNIKOV. 1964. (PROGRAMMING THE CROSS-CUTTING OF TREE-LENGTH LOGS.) LESN. PROM. (10):6-8. (IN RUSSIAN.) SATISFACTORY CROSS-CUTTING PROGRAMS CAN BE WORKED OUT FOR TREE-LENGTH LOGS IF THE SPECIES, HEIGHT CLASS, AND LOG LENGTH ARE KNOWN; AN EXAMPLE OF SUCH A PROGRAM FOR SOFTWOODS IS GIVEN. COMPARISON OF THE YIELD FROM AUTOMATED CROSS-CUTTING BY THIS PRESET PROGRAM AND BY THE USUAL VISUAL-INDIVIDUAL

- METHOD, SHOWED THAT THE PROGRAMMED METHOD MARKEDLY INCREASED PRODUCTIVITY AND CAUSED VIRTUALLY NO REDUCTION IN THE AMOUNT OF LUMBER OBTAINED.
194. LAWRENCE, J. D. 1969. DATA COLLECTION AND STATISTICAL ANALYSIS OF OPERATIONS RESEARCH INPUT DATA. OPER. RES. APPL. TO SAWMILLS PROC.:19-23, UNIV. GEORGIA, ATHENS. DATA COLLECTION IS AN IMPORTANT PHASE OF OPERATIONS RESEARCH. DATA ARE USED TO DEVELOP FUNCTIONAL RELATIONSHIPS THAT PREDICT PROCESSING TIME AND YIELDS OF OUTPUTS. REGRESSION ANALYSIS IS A USEFUL TOOL IN THE DEVELOPMENT OF THESE FUNCTIONAL RELATIONSHIPS FOR GENERATING LINEAR PROGRAM INPUT DATA.
195. LAWRENCE, J. D. 1969. INITIAL INVESTMENT AND MAINTENANCE COSTS OF A MATHEMATICAL PROGRAMMING ANALYSIS. OPER. RES. APPL. TO SAWMILLS PROC.:45-49, UNIV. GEORGIA, ATHENS. COST OF A MATHEMATICAL PROGRAMMING ANALYSIS DEPENDS UPON THE COMPLEXITY OF THE MODEL FORMULATED AS DETERMINED BY THE OBJECTIVES OF MANAGEMENT. THIS PAPER EXPLAINS INITIAL COSTS AT TWO LEVELS FOR EACH OF 10 PHASES DEFINED WITHIN THE OPERATIONS RESEARCH PROCEDURE: "OPTIMISTIC" -- WHEN THE USER HAS SOME FAMILIARITY WITH OPERATIONS RESEARCH APPLICATIONS; AND "EXPECTED" -- WHEN THE USER IS LESS FAMILIAR WITH THESE APPLICATIONS.
196. LEAK, W. B. 1964. ESTIMATING MAXIMUM ALLOWABLE TIMBER YIELDS BY LINEAR PROGRAMMING. USDA FOREST SERV. NE FOREST EXP. STA. RFS. PAP. NE-17, 9 PP. UPPER DARBY, PA. A PRESENTATION OF GENERAL EQUATIONS, AND ILLUSTRATION OF THE USE OF LINEAR PROGRAMMING IN COMPLEX MANAGEMENT SITUATIONS, WITH TWO HYPOTHETICAL EXAMPLES.
197. LEAK, W. B. 1964. SOME COMMENTS ON "THE DEVELOPMENT OF AN OPTIMAL PROGRAM FOR SUSTAINED-YIELD MANAGEMENT". J. FOREST. 62(11):828-829. A CRITICAL REVIEW OF THE LONG-TERM PLANNING AND SCHEDULING OF YIELDS FROM PARTIALLY-CUT STANDS IN THE LINEAR PROGRAMMING METHODS APPLIED IN D. P. LOUCK'S ARTICLE (J. FOREST. 62(7):485-490, JULY 1964).
198. LEAK, W. B. 1968. BIRCH REGENERATION: A STOCHASTIC MODEL. USDA FOREST SERV. NE FOREST EXP. STA. RFS. NOTE NE-85, 7 PP. UPPER DARBY, PA. THE REGENERATING OF A CLEAR FELLING WITH PAPER OR YELLOW BIRCH IS EXPRESSED IN AN ELEMENTARY STOCHASTIC (PROBABILISTIC) MODEL THAT IS COMPUTATIONALLY SIMILAR TO AN ABSORBING

MARKOV-CHAIN. IN THE GENERAL CASE, THE MODEL CONTAINS 29 STATES, BEGINNING WITH THE DEVELOPMENT OF A FLOWER (AMENT) AND TERMINATING WITH THE ABORTION OF A FLOWER OR SEED, OR THE DEVELOPMENT OF AN ACCEPTABLE STEM, UNACCEPTABLE STEM, DEAD SEEDLING, OR NONGERMINATE (THE SIX ABSORBING STATES). EXPRESSIONS ARE GIVEN FOR THE EXPECTED MEAN NUMBER OF OCCURRENCES OF EACH STATE, AND THE PROBABILITY OF ARRIVING AT ANY ABSORBING STATE AFTER THE OCCURRENCE OF ANY TRANSIENT STATE.

199. LEAK, W. B. 1970. SAPLING STAND DEVELOPMENT: A COMPOUND EXPONENTIAL PROCESS. FOREST SCI. 16(2):177-180. THE DEVELOPMENT OF AN EVEN-AGED STAND DURING THE SAPLING STAGE IS EXPRESSED AS A THEORETICAL STOCHASTIC MODEL REFERRED TO AS THE COMPOUND EXPONENTIAL PROCESS. GIVEN A SUITABLE ESTIMATE OF THE ONE PARAMETER OF THE PROCESS, WE CAN PREDICT THE PROBABILITIES AND EXPECTATIONS OF FUTURE NUMBERS OF TREES BY DIAMETER CLASSES. THE PROCESS APPEARS TO HAVE INTERESTING IMPLICATIONS TO THE PROBLEM OF EVALUATING THE FUTURE STOCKING OF REGENERATION OR SAPLING STANDS.
200. LEAK, W. B., AND S. M. FILIP. 1970. CUTTING STRATEGIES AND TIMBER YIELDS FOR UNBALANCED EVEN-AGED NORTHERN HARDWOOD FORESTS. USDA FOREST SERV. NE FOREST EXP. STA. RES. PAP. NE-153, 19 PP., UPPER DARBY, PA. LINEAR PROGRAMMING IS USED TO DEVELOP CUTTING STRATEGIES FOR FOUR HYPOTHETICAL EVEN-AGED NORTHERN HARDWOOD FORESTS WITH UNBALANCED AGE DISTRIBUTIONS THAT MAXIMIZE BOARD-FOOT YIELDS AND PRODUCE BALANCED AGE DISTRIBUTIONS BY THE END OF THE FIRST ROTATION. MANAGED (THINNED) AND UNMANAGED (CLEARCUTTING ONLY) APPROACHES ARE COMPARED, REVEALING LARGE DIFFERENCES IN BOARD-FOOT YIELDS.
201. LEARY, R. A. 1970. SYSTEM IDENTIFICATION PRINCIPLES IN STUDIES OF FOREST DYNAMICS. USDA FOREST SERV. N. CENTRAL FOREST EXP. STA. RES. PAP. NC-45, 38 PP., ST. PAUL, MINN. NONLINEAR ORDINARY DIFFERENTIAL EQUATIONS ARE USED TO DESCRIBE SYSTEM DEVELOPMENT, AND EQUATION PARAMETERS ARE ESTIMATED BY CONSIDERING OBSERVATIONS AS BOUNDARY CONDITIONS IN A NONLINEAR MULTIPONT BOUNDARY VALUE PROBLEM. APPLICATIONS ARE MADE TO FOREST STAND DEVELOPMENT.
202. LEE, YAM. 1967. STAND MODELS FOR LODGEPOLE PINE AND LIMITS TO THEIR APPLICATION. PH.D. THESIS, UNIV. BRITISH COLUMBIA, VANCOUVER, CAN. NEWNHAM'S SIMULATION STAND MODELS ARE CRITICALLY EXAMINED AND FULLY DESCRIBED. A REVISED SIMULATION MODEL

IS BUILT FOR LODGEPOLE PINE STAND GROWTH AND THE METHODS USED ARE DESCRIBED. THE MODEL CAN BE USED TO SIMULATE THE GROWTH OF MANY KINDS OF LODGEPOLE PINE STANDS FROM AGE 15 TO AGE 100, OR MORE.

203. LENHART, J. D. 1965. SIMULATION OF BUSCHCOMBINE OPERATIONS IN SLASH PINE PLANTATIONS. UNPUBL. M.S. THESIS, UNIV. GEORGIA, ATHENS. PERFORMANCE CHARACTERISTICS OF TWO BUSCHCOMBINES OPERATED BY UNION BAG-CAMP CORPORATION WERE EVALUATED BY USING COMPUTER SIMULATION TECHNIQUES. THE O PAPER CORPORATION WERE EVALUATED BY USING COMPUTER SIMULATION TECHNIQUES. THE OBJECTIVE WAS TO DETERMINE PRODUCTION RATES FOR BUSCHCOMBINES OPERATING IN SLASH PINE PLANTATIONS OF VARYING STAND AGES, SITE QUALITIES, AND STAND DENSITIES. A WIDE RANGE OF PRODUCTION RATES WERE CALCULATED BY ITERATIVE TECHNIQUES USING THE SIMULATION MODEL WITH THE VARYING STAND PARAMETERS.
204. LEONTIEF, W. W. 1951. THE STRUCTURE OF AMERICAN ECONOMY, 1919-1939. ED. 2, 264 PP., ILLUS. NEW YORK: OXFORD UNIV. PRESS. THIS IS THE ORIGINAL WORK CONCERNED WITH INPUT-OUTPUT MODELS.
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SKIDDING, AND ITS OPERATION IS INCLUDED.

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PROVIDING NON-MARKET BENEFITS.

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GROUPS AND AN EXHAUSTIVE BIBLIOGRAPHY ON QUEUING THEORY ARE INCLUDED.

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COMPUTER PROGRAM IS DEVELOPED, BASED ON A REPRESENTATIVE MILL SETUP FOR STUD (SCATLING) PRODUCTION IN NORTH COASTAL CALIFORNIA. ITS APPLICATIONS TO CHANGING CONDITIONS AND TO OTHER ASPECTS OF THE FOREST-PRODUCTS INDUSTRY ARE DISCUSSED.

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250. MIERNYK, W. H. 1965. THE ELEMENTS OF INPUT-OUTPUT ANALYSIS. ED. 2, 156 PP. NEW YORK: RANDOM HOUSE.

CHAPTERS ON: INPUT-OUTPUT ANALYSIS, APPLICATIONS OF INPUT-OUTPUT ANALYSIS, REGIONAL AND INTERREGIONAL INPUT-OUTPUT ANALYSIS, INTERNATIONAL DEVELOPMENTS, THE FRONTIERS OF INPUT-OUTPUT ANALYSIS, AND THE RUDIMENTS OF INPUT-OUTPUT MATHEMATICS.

251. MITCHELL, K. J. 1967. SIMULATION OF THE GROWTH OF EVEN-AGED STANDS OF WHITE SPRUCE. PH.D. DISS., YALE UNIV., NEW HAVEN, CONN. A COMPARISON OF THE ACTUAL AND SIMULATED GROWTH OF PERMANENT SAMPLE PLOTS SHOWED CLOSE AGREEMENT IN TERMS OF BOLE AND CROWN PARAMETERS. THE MODEL IS DESIGNED TO REPLACE CONVENTIONAL YIELD TABLES AND PROVIDE A TOOL FOR TESTING SILVICULTURAL PRACTICES AND MANAGEMENT PLANS. IT CAN BE APPLIED OVER LARGE AREAS WITH INFORMATION FROM LOW-LEVEL AERIAL PHOTOGRAPHS, THUS EXPEDITING THE COLLECTION OF DATA.
252. MITCHELL, K. J. 1969. SIMULATION OF THE GROWTH OF EVEN-AGED STANDS OF WHITE SPRUCE. YALE UNIV. SCHOOL FORESTRY, BULL, 75, 48 PP., NEW HAVEN, CONN. SEE PREVIOUS ANNOTATION.
253. MUSZYNSKI, Z. 1966. (THE APPLICATION OF LINEAR PROGRAMMING TO THE REGIONAL DISTRIBUTION OF TIMBER DISPATCHING FROM DEPOTS TO WOODWORKING PLANTS.) SYLWAN 110(2):27-40. (IN POLISH.) A BETTER ANALYSIS IS SOUGHT FOR THE PROBLEM OF REGIONAL DISTRIBUTION OF WOOD SUPPLIES, BASED UPON THE CRITERION OF THE MINIMIZATION OF THE TOTAL NUMBER OF TON-KILOMETERS. THE SPACING METHOD, AN LP TECHNIQUE, IS USED TO SOLVE AN EXAMPLE PROBLEM OF M DEPOTS DISPATCHING A/I WOOD TO N WOODWORKING PLANTS, TO WHICH B/J UNITS OF THE SAME ASSORTMENTS ARE BEING DELIVERED.
254. MYERS, C. A. 1968. SIMULATING THE MANAGEMENT OF EVEN-AGED TIMBER STANDS. (REV. 1969) USDA FOREST SERV. ROCKY MT. FOREST AND RANGE EXP. STA. RES. PAP. RM-42, 32 PP. FORT COLLINS, COLORADO. THE PRESENTATION OF A COMPUTER PROGRAM, WRITTEN IN FORTRAN IV, FOR SIMULATING THE MANAGEMENT OF EVEN-AGED TIMBER STANDS. CHANGES THAT WERE COMPUTED INCLUDE TREE GROWTH, HARVEST CUTS, PERIODIC THINNINGS, AND CATASTROPHIC LOSSES. ANNUAL COSTS AND RETURNS ARE SUMMARIZED IN VARIOUS STATEMENTS OF MONEY VALUE.
255. NAGIUMO, H., AND H. MINOWA. 1967. (ANALYSIS OF THE REGULATION OF YIELD BY LINEAR PROGRAMMING.) TOKYO UNIV. FOREST. BULL. 63:235-265. (IN JAPANESE)

WITH ENGLISH SUMMARY.) THEORETICAL EQUATIONS ARE PRESENTED FOR CALCULATING THE MAXIMUM TOTAL YIELD FROM A FOREST COMPOSED OF EVEN-AGED STANDS OF SIMILAR SPECIES MANAGED UNDER A CLEAR-FELLING SYSTEM. THEIR FIELD APPLICATION IS ALSO EXAMINED UNDER VARIOUS CONDITIONS.

256. NAGUMO, H., AND Y. HIRONAKA. 1968. (AN APPLICATION OF LINEAR PROGRAMMING TO THE EXPLOITATION OF NATURAL FORESTS (I) AND (II).) TRANSL. DEP. FOR. CAN., NO. 260, 10 PP., AND NO. 261, 12 PP. (IN JAPANESE.) THE LP METHOD IS USED TO DETERMINE THE MOST ECONOMICAL PLAN FOR ROAD CONSTRUCTION IN, AND EXPLOITATION OF, A HITHERTO UNEXPLOITED (INACCESSIBLE) 4000-HA. PRIVATE FOREST IN CENTRAL HONSHU.
257. NAUTIYAL, J. C. 1966. OPTIMUM RATE OF FOREST HARVESTING. FOREST CHRON. 42(4):337-345. OUTLINES ECONOMIC CONDITIONS THAT MUST HOLD GOOD FOR: (1) AN EFFICIENT ALLOCATION OF PRIMARY FACTORS OF PRODUCTION FOR HARVESTING FOREST RESOURCES, AND (2) ALLOCATION OF THESE RESOURCES BETWEEN PRESENT AND FUTURE USE. THE CONCEPT OF USER COST IS APPLIED TO SPECIFY TEMPORAL EFFICIENCY IN HARVESTING OF RESOURCES, AND A PRACTICAL METHOD FOR COMPUTING THIS COST IS DEVELOPED. LINEAR PROGRAMMING IS APPLIED TO MAXIMIZE THE PRESENT WORTH OF A FOREST WHILE CONVERTING IT TO SUSTAINED YIELD.
258. NAUTIYAL, J. C., AND P. H. PEARSE. 1967. OPTIMIZING THE CONVERSION TO SUSTAINED YIELD: A PROGRAMMED SOLUTION. FOREST SCI. 13(2):131-139. THIS PAPER DEMONSTRATES HOW LINEAR PROGRAMMING TECHNIQUES CAN BE USED TO SPECIFY THE ECONOMIC OPTIMUM PATTERN OF HARVESTS FROM AN IRREGULAR FOREST DURING THE PERIOD OF ITS CONVERSION TO SUSTAINED YIELD.
259. NAVON, D. J. 1967. COMPUTER-ORIENTED SYSTEMS FOR WILDLAND MANAGEMENT. J. FOREST. 65(7):473-479. INCREASING COMPETITION AMONG GRAZING, RECREATION, TIMBER, AND WATER PRODUCTION MAKES IMPERATIVE THE RATIONAL ALLOCATION OF WILDLAND RESOURCES AMONG THESE USES. ANY METHOD USED TO ALLOCATE RESOURCES MUST BE CAPABLE OF ADJUSTING ITS SOLUTION TO CHANGES IN ESTIMATED AND ECOLOGICAL RELATIONSHIPS AS WELL AS IN THE PROJECTED PATTERN OF DEMAND. A COMPUTER DATA-PROCESSING SYSTEM INTEGRATED WITH A LINEAR-PROGRAMMING ALLOCATION MODEL IS CAPABLE OF MEETING THIS CHALLENGE. THE MAP INFORMATION ASSEMBLY AND DISPLAY SYSTEM (MIADS) IS PRESENTED

AS A COMPUTERIZED DATA-PROCESSING SYSTEM.

260. NAVON, D. I., AND R. J. MCCONNEN. 1967. EVALUATING FOREST MANAGEMENT POLICIES BY PARAMETRIC LINEAR PROGRAMMING, USDA FOREST SERV. PACIFIC SW FOREST AND RANGE EXP. STA. RES. PAP. PSW-42, 13 PP., BERKELEY, CALIF. AN ANALYTICAL AND SIMULATION TECHNIQUE, PARAMETRIC LINEAR PROGRAMMING EXPLORES ALTERNATIVE CONDITIONS AND DEVISES AN OPTIMAL MANAGEMENT PLAN FOR EACH CONDITION. APPLICATION IN SOLVING POLICY AND DECISION PROBLEMS IN THE MANAGEMENT OF FOREST LANDS IS ILLUSTRATED.
261. NAYLOR, T. H., J. L. BALINTFY, D. S. BURDICK, AND K. CHU. 1966. COMPUTER SIMULATION TECHNIQUES. 352 PP. NEW YORK: JOHN WILEY & SONS, INC. CHAPTERS ON : INTRODUCTION TO COMPUTER SIMULATION; PLANNING COMPUTER SIMULATION EXPERIMENTS; TECHNIQUES FOR GENERATING RANDOM NUMBERS; ELEMENTS OF NUMBER THEORY; GENERATION OF STOCHASTIC VARIATES FOR SIMULATION; COMPUTER MODELS OF QUEUING, INVENTORY, AND SCHEDULING SYSTEMS; SIMULATION OF ECONOMIC SYSTEMS; SIMULATION LANGUAGES; THE PROBLEM OF VERIFICATION; AND DESIGN OF SIMULATION EXPERIMENTS.
262. NEMHAUSER, GEORGE L. 1966. INTRODUCTION TO DYNAMIC PROGRAMMING. 256 PP. NEW YORK: JOHN WILEY & SONS, INC. CONTENTS INCLUDE: BASIC THEORY; BASIC COMPUTATIONS; COMPUTATIONAL REFINEMENTS; RISK, UNCERTAINTY AND COMPETITION; NONSERIAL SYSTEMS; INFINITE-STAGE SYSTEMS.
263. NEUBURGER, A. 1965. REPORT OF A STUDY INTO THE USE OF AIRCRAFT IN THE CONTROL OF FOREST FIRES. XV, 211 PP. UNITED AIRCRAFT OF CAN., LTD., LONGUEUIL, QUE. FROM THE PARAMETRIC RELATIONSHIPS DERIVED, A MODEL IS CONSTRUCTED THAT GIVES A METHOD OF COMPUTING FINAL FIRE SIZE, TIME REQUIRED FOR SUPPRESSION, NUMBER OF MEN NECESSARY, ETC. THE INFORMATION FOR MODEL DEVELOPMENT WAS OBTAINED FROM PAST CANADIAN FIRE RECORDS.
264. NEVALAINEN, M. 1969. (THE APPLICATION OF LINEAR PROGRAMMING IN AN INTEGRATED WOODWORKING COMPANY.) PAP. JA PAU. 51(8):606-609. (IN, FINNISH, SUMMARY IN ENGLISH.) A LP MODEL WAS DEVELOPED TO DETERMINE THE MOST PROFITABLE DISTRIBUTION OF AVAILABLE TIMBER TO THE PRODUCTION OF PLYWOOD, LUMBER, WOODEN SPOOLS, AND SULPHATE AND SULPHITE PULPS. A SIMPLE MATRIX REPRESENTATION OF THE MODEL IS INTRODUCED AND THE APPLICATION OF THE MODEL IS DISCUSSED.

265. NEWNHAM, R. M. 1966. THE DEVELOPMENT OF A STAND MODEL FOR DOUGLAS-FIR. DISS. ABSTR. 26(7):3567-8. A DESCRIPTION OF THE DEVELOPMENT OF A MATHEMATICAL MODEL, WHICH SATISFACTORILY REPRESENTS TREE GROWTH (ESPECIALLY DIAMETER GROWTH AND ITS RELATION TO CROWN WIDTH) IN STANDS AGED 10 TO 100 YEARS. THE MODEL ENHRACES A WIDE RANGE OF SITE CONDITIONS, STAND DENSITIES, AMOUNTS AND DISTRIBUTIONS OF MORTALITY, AND THINNING REGIMES.
266. NEWNHAM, R. M. 1966. A SIMULATION MODEL FOR STUDYING THE EFFECT OF STAND STRUCTURE ON HARVESTING PATTERN. FORESTRY CHRON. 42(1):39-44. A SIMPLE SIMULATION MODEL IS DESCRIBED WHICH IMITATES THE PASSAGE OF A MECHANICAL HARVESTER THROUGH A PULPWOOD STAND. USING THIS MODEL, WHICH HAS BEEN PROGRAMMED FOR AN IBM 1620 COMPUTER, IT IS POSSIBLE TO STUDY THE EFFECT THAT STAND STRUCTURE AND MACHINE SIZE HAVE ON HARVESTING PATTERN. MODIFICATIONS TO THE MODEL TO INCLUDE ESTIMATES OF OPERATING TIME ARE SUGGESTED.
267. NEWNHAM, R. M. 1967. A FORTRAN PROGRAM TO SIMULATE PULPWOOD HARVESTING MACHINES. FOREST MANAGE. RES. SERV. INST. INFORM. RPT. FMR-X-7, 32 PP., OTTAWA, ONT., CAN. THE COMPUTER PROGRAM AND DESCRIPTION OF ITS USE.
268. NEWNHAM, R. M. 1967. A PROGRESS REPORT ON THE SIMULATION MODEL FOR PULPWOOD HARVESTING MACHINES. CANADA DEP. FORESTRY AND RURAL DEVELOP. INFORM. RPT. FMR-X-6, 41 PP. A MODEL, PROGRAMMED FOR AN IBM SYSTEM/360 COMPUTER IS DESCRIBED WHICH SIMULATES THE PASSAGE OF A FELLER-BUNCHER, SUCH AS THE L.R.A. FELLER-BUNCHERS AND THE BELOIT TYPE OF TREE HARVESTER, THROUGH A STAND OF PULPWOOD.
269. NEWNHAM, R. M. 1968. THE GENERATION OF ARTIFICIAL POPULATIONS OF POINTS (SPATIAL PATTERNS) ON A PLANE. FOREST MANAGE. INST. INFORM. REP. FMR-X-10, 28 PP. OTTAWA, ONT., CAN. A NEW METHOD OF GENERATING ARTIFICIAL POPULATIONS OF POINTS BY USING AN IBM SYSTEM/360 COMPUTER IS DESCRIBED. THE STUDY WAS UNDERTAKEN AS PART OF A PROJECT TO SIMULATE THE OPERATION OF HARVESTING MACHINES IN PULPWOOD STANDS IN WHICH THE SPATIAL PATTERNS OF THE TREES WAS ONE OF THE VARIABLES TESTED. THE METHOD PRODUCES A RANGE OF SPATIAL PATTERNS VARYING FROM UNIFORM (REGULAR) THROUGH RANDOM TO CLUMPED (AGGREGATED). THE COMPUTER PROGRAM FOR THE POPULATION GENERATOR CAN ALSO DRAW UP POPULATION MAPS WITH A CALCOMP PLOTTER.

270. NEWNHAM, R. M. 1968. MINIMUM MERCHANTABLE TREE SIZE AND MACHINE PRODUCTIVITY - A SIMULATION STUDY. PULP AND PAPER MAG. OF CAN. 69(100):227-229. THE RESULTS OF A SIMULATION STUDY TO TEST THE EFFECT ON HARVESTING-MACHINE PRODUCTIVITY OF VARYING THE MINIMUM MERCHANTABLE DIAMETER. THE TEST WAS CONDUCTED IN STANDS CONTAINING 150, 300, AND 450 TREES PER ACRE. MINIMUM MERCHANTABLE DIAMETER WAS TESTED AT 1-INCH INTERVALS BETWEEN 5 AND 11 INCHES. RESULTS SHOWED THAT HARVESTING TIME PER UNIT REACHED A MINIMUM BETWEEN 9 AND 10 INCHES AND THEN INCREASED AGAIN.
271. NEWNHAM, R. M. 1968. SIMULATION MODELS IN FOREST MANAGEMENT AND HARVESTING. FOREST. CHRON. 44(1):7-12. THE ADVANTAGES AND DISADVANTAGES OF SIMULATION MODELS ARE DESCRIBED AND EXAMPLES ARE GIVEN OF THEIR USE IN FORESTRY. STAND MODELS AND A SIMULATION MODEL FOR PULPWOOD-HARVESTING MACHINES ARE DESCRIBED IN SOME DETAIL.
272. NEWNHAM, R. M. 1969. SIMULATION OF PULPWOOD HARVESTING MACHINES. FOREST ENG. CONF. PROC. 1968:71-73, 111. MICH. STATE UNIV., E. LANSING. A DESCRIPTION OF PAST WORK ON A SIMULATION MODEL FOR MACHINES SUCH AS THE BELOIT TREE HARVESTER AND THE L.R.A. LOG-ALL. SOME OF THE DEVELOPMENTS AND MODIFICATIONS OF THE SIMULATOR TO HANDLE A GREATER VARIETY OF STAND THINNING EQUIPMENT ARE PRESENTED IN DETAIL.
273. NEWNHAM, R. M. 1970. PRODUCTIVITY OF HARVESTING MACHINES DESIGNED FOR THINNING: ESTIMATION BY SIMULATION. FOREST MANAGE. INST. INFORM. RPT. FMR-X-25, OTTAWA, ONT. CAN., 29 PP. BY EMPLOYING A MECHANIZED THINNING SIMULATOR (NEWNHAM AND SJUNNESSON, 1969), THE PARAMETERS DESCRIBING THE B105 FELLER-PROCESSOR AND ITS OPERATION HAVE BEEN TESTED OVER A RANGE OF VALUES TO ESTIMATE POTENTIAL PRODUCTIVITY OF THE MACHINE AND TO SUGGEST POSSIBLE IMPROVEMENTS IN ITS DESIGN. MAXIMUM BOOM REACH, STRIP WIDTH, DELAY TIME, BOOM IN/OUT SPEED, AND BOOM SLEWING SPEED WERE THE MOST CRITICAL FACTORS IN INFLUENCING PRODUCTIVITY. IMPROVEMENTS IN THE HARVESTING MACHINE FOR DECREASING FELLING CYCLE TIME ARE ALSO RECOMMENDED.
274. NEWNHAM, R. M., AND G. T. MALOLEY. 1970. THE GENERATION OF HYPOTHETICAL FOREST STANDS FOR USE IN SIMULATION STUDIES. CAN. FOREST SERV. FOREST MANAGE. INST. INFORM. REP. FMR-X-26, 73 PP. A MATHEMATICAL MODEL, PROGRAMMED IN FORTRAN IV FOR A

UNIVAC 1108 COMPUTER IS DESCRIBED THAT GENERATES HYPOTHETICAL FOREST STANDS. INPUT CONSISTS OF SPATIAL PATTERNS REPRESENTING THE TREES, AND THE MEAN AND STANDARD DEVIATION OF EACH TREE VARIABLE (D.B.H., HEIGHT, CROWN LENGTH). THE MODEL SHOULD BE ABLE TO PRODUCE REALISTIC STANDS FOR A VARIETY OF SIMULATION STUDIES.

275. NEWNHAM, R. M., AND S. SJUNNESSON. 1969. A FORTRAN PROGRAM TO SIMULATE HARVESTING MACHINES FOR MECHANIZED THINNING. FOREST MANAGE. INST., INFORM. RPT. FMR-X-23, OTTAWA, ONT., CAN. A COMPUTER PROGRAM WRITTEN IN FORTRAN IV IS DESCRIBED THAT SIMULATES THE PASSAGE OF A HARVESTING MACHINE THROUGH A FOREST STAND THAT IS BEING THINNED. THE PROGRAM STUDIES THE EFFECT OF MACHINE SIZE AND CONFIGURATION, AND OPERATING SPEEDS ON PRODUCTIVITY. THE MODEL MAY BE USED TO SIMULATE FELLER-PROCESSORS, FELLER-BUNCHERS, OR STRIROAD PROCESSORS. DATA REQUIREMENTS ARE GIVEN AS WELL AS SAMPLE INPUT AND OUTPUT.
276. NEWNHAM, R. M., AND SMITH, J. H. G. 1964. DEVELOPMENT AND TESTING OF STAND MODELS FOR DOUGLAS-FIR AND LODGEPOLE PINE. FOREST. CHRON. 40(4):494-502. METHODS USED IN THE DEVELOPMENT AND TESTING OF STAND MODELS FOR DOUGLAS-FIR AND LODGEPOLE PINE ARE DESCRIBED BRIEFLY. THE IMPORTANCE OF KNOWING DISTRIBUTION AS WELL AS AMOUNT OF MORTALITY IS STRESSED AND ILLUSTRATED. USE OF THE MODEL FOR STUDYING THINNING IS DESCRIBED. THESE MODELS ARE EASILY MANIPULATED TO PROVIDE SIMULATION ANALYSES ON A COMPUTER.
277. NORMAN, E. L. 1968. A LINEAR PROGRAM FOR FOREST PRODUCTION CONTROL. M.S. THESIS, UNIV. GA., ATHENS. THIS STUDY WAS AN ATTEMPT TO REFINISH AND QUANTIFY THE BASES FOR MANAGEMENT DECISIONS INVOLVING THE REGULATION OF UNEVEN-AGED HARDWOODS ON THE FORESTED LANDS OF THE OAK RIDGE NATIONAL LABORATORY IN NORTHEASTERN TENNESSEE. THE OBJECTIVE FUNCTION OF THE LP PROBLEM WAS TO SCHEDULE THE PRESENT HARVEST TO MAXIMIZE THE VALUE OF THE RESIDUAL STAND AT THE TIME OF THE NEXT CUTTING CYCLE DISCOUNTED TO THE PRESENT.
278. NORMAN, E. L., AND J. W. CURLIN. 1968. A LINEAR PROGRAMMING MODEL FOR FOREST PRODUCTION CONTROL. OAK RIDGE NAT. LAB. REP. 4349, 48 PP. OAK RIDGE, TENNESSEE. A MATHEMATICAL MODEL IS PRESENTED THAT ANNUALLY OPTIMIZES THE CUTTING SCHEDULE IN TWO ARBITRARILY SELECTED COMPARTMENTS ON THE OAK RIDGE RESERVATION. YIELD EQUATIONS WERE DEVELOPED

FOR THREE MAJOR TIMBER TYPES; AND SITE QUALITY WAS USED AS AN INDEPENDENT VARIABLE IN THE YIELD EQUATIONS. THE OBJECTIVE FUNCTION WAS MAXIMIZED OVER ONE CUTTING PERIOD (12 YEARS), AND SELECTED MANAGEMENT ALTERNATIVES WERE PROPOSED AND EVALUATED SUBJECT TO VARIOUS MANAGEMENT RESTRICTIONS. THE MODEL SELLECTS FOR CUTTING THOSE ALTERNATIVES THAT MAXIMIZE THE VALUE OF THE RESIDUAL STAND DISCOUNTED TO THE PRESENT.

279. NOVOTNY, M. 1967. (MANAGEMENT PROBLEMS OF ENTERPRISE TRANSPORT AND THE APPLICATION OF LINEAR PROGRAMMING.) COMMUN. INST. FOR. CSL, 5:203-212. (ENGLISH, SUMMARY IN RUSSIAN.) AN ENGLISH VERSION OF THE PREVIOUS CITATION.
280. NOVOTNY, M. 1967. (POSSIBILITIES FOR THE APPLICATION OF LINEAR PROGRAMMING IN LOG HAULING IN FOREST ENTERPRISES.) CZECH. MIN. ZEMED. LES. HOSPOD. USTAV, VEDECKOTECH., INFORM. LES. CAS. 40(9):769-784. (CZECHOSLOVAKIAN, ENGLISH SUMMARY.) LINEAR PROGRAMMING IS SUCCESSFULLY APPLIED AS THE DECISION MAKING ALGORITHM IN THE HAULING OF TIMBER IN FOREST MANAGEMENT UNITS.
281. NOVOTNY, M., AND J. MERVART. 1969. (THE USE OF LINEAR PROGRAMMING IN ECONOMIC ANALYSES OF TIMBER TRANSPORT.) LESNICTVI 15(6):475-484. (CZECHOSLOVAKIAN, SUMMARIES IN RUSSIAN, ENGLISH, GERMAN, AND FRENCH.) WORK RECORDS FROM SEVEN FOREST ENTERPRISES IN CZECHOSLOVAKIA ARE USED TO GIVE TWO EXAMPLES OF APPLYING LINEAR PROGRAMMING TO IMPROVE THE ECONOMIC ORGANIZATION OF TIMBER TRANSPORT, VIZ., (1) ON THE LEVEL OF THE INDIVIDUAL ENTERPRISE, AND (2) ON THE LEVEL OF THE MANAGEMENT UNIT AS A WHOLE.
282. O'REGAN, W. G. 1966. A SIMULATION APPROACH TO TIMBER MANAGEMENT. SEMINAR ON OPER. RES. IN FOREST PROD. IND. PROC.; 113-132. IBM CORP., LOS ANGELES, CALIF. TWO SIMULATION MODELS ARE DEVELOPED FOR USE IN STUDYING AND TEACHING TIMBER-MANAGEMENT DECISION-MAKING. PRELIMINARY AND ILLUSTRATIVE RESULTS ARE PRESENTED FOR SOME SIMPLE MANAGEMENT PLANS.
283. O'REGAN, W. G., AND L. G. ARVANITIS. 1969. SAMPLING SIMULATION COMPUTER PROGRAM. II. COST EFFECTIVENESS AND SAMPLING EFFICIENCY. UNIV. WISC. COLL. AGR. & LIFE SCI. RES. REP. 50, 31 PP., MADISON. THE APPLICATION OF A COST-EFFECTIVENESS APPROACH TO FOREST SAMPLING IS DEMONSTRATED BY A NEW FORTRAN IV COMPUTER PROGRAM. THE INPUT

INFORMATION INCLUDES THE VARIANCE OF AN ESTIMATOR AS A FUNCTION OF PLOT AREAS OR BASAL AREA FACTORS, AND A COST FUNCTION. CONCEPTS OF PRODUCTION ECONOMICS ARE USED TO IDENTIFY OPTIMUM COMBINATIONS OF PLOT NUMBERS OR POINTS AND CERTAIN SAMPLING RULES. THE OBJECTIVE IS TO MINIMIZE THE VARIABLE COST OF SAMPLING FOR A DESIRED PRECISION LEVEL.

284. O'REGAN, W. G., AND M. N. PALLEY. 1965. A COMPUTER TECHNIQUE FOR THE STUDY OF FOREST SAMPLING METHODS. FOREST SCI. 11(1):99-114. A REPORT ON THE RESULTS OF USING A COMPUTER PROGRAM TO SIMULATE CIRCULAR- PLOT SAMPLING OF FOREST STANDS. THE CHARACTERISTICS OF INTEREST IN THESE STANDS ARE (1) TOTAL FREQUENCY, (2) TOTAL DIAMETER, (3) TOTAL BASAL AREA, AND (4) TOTAL VOLUME.
285. O'REGAN, W. G., L. G. ARVANITIS, AND E. M. GOULD, JR. 1966. SYSTEMS, SIMULATION, AND FOREST MANAGEMENT. SOC. AMER. FOREST. PROC. 1965: 194-198. DETROIT, MICH. A REPORT OF WORK ON TWO COMMON PROBLEMS FACED BY FORESTERS: (1) THE SEARCH FOR EFFECTIVE METHODS OF GATHERING DATA-MAXIMIZING SAMPLING INFORMATION FROM A FIXED BUDGET, AND (2) THE DEVELOPMENT OF SIMULATORS TO CLARIFY MANAGEMENT OPTIONS-CONSTRUCTION OF A FOREST MODEL REGARDED AS A 'WOOD GENERATOR.'
286. DVERTON, C. E. 1969. A MODEL FOR DEVELOPING MANAGEMENT PLANS AND PLANNING CRITERIA FOR MULTI-ENTERPRISE, NON-RESIDENT OWNERS OF LARGE INTERMINGLED LAND HOLDINGS. M.S. THESIS, PURDUE UNIV., LAFAYETTE, IND. A LINEAR PROGRAMMING MODEL IS DEVELOPED TO AID THE SHORT-RUN MANAGEMENT PLANNING OF LARGE LAND HOLDINGS MADE UP OF WIDELY SCATTERED FARM-FORESTRY ENTERPRISES.
287. PAYNE, D. W. M. 1966. ANALYSIS OF A FOREST MANAGEMENT SITUATION BY LINEAR PROGRAMMING. AUST. FOREST. 30(4):293-303. ANALYSIS OF A FOREST BY LINEAR PROGRAMMING TO DETERMINE THE OPTIMUM HARVESTING PROGRAM, FOR LEAST REDUCTION OF CURRENT SAWTIMBER GROWTH, PRODUCED RESULTS THAT WERE SUITABLE FOR USE IN THE FIELD AS A SET OF PRESCRIPTIONS FOR TREE MARKING. SUPPLEMENTARY ANALYSIS BY PARAMETRIC PROGRAMMING SHOWED THE EFFECTS OF VARYING SOME OF THE FACTORS INVOLVED.
288. PARKER, H. V., III. 1969. THE APPLICATION OF LINEAR PROGRAMMING OPTIMIZATION TECHNIQUES TO KRAFT PULP AND PAPER MILL EFFLUENT TREATMENT. M.S. THESIS, N. C. STATE UNIV., RALEIGH. TWO APPROACHES ARE

PRESENTED TO THE OPTIMIZATION OF KRAFT PULP AND PAPER MILL EFFLUENT TREATMENT SYSTEMS. LINEAR PROGRAMMING MODELS ARE DEVELOPED TO DESCRIBE THE ENTIRE SYSTEM, INCLUDING THE MILL, THE EFFLUENT TREATMENT PLANT, AND THE RIVER. THE FIRST APPROACH ATTEMPTS TO MINIMIZE THE COST OF EFFLUENT TREATMENT, AND THE SECOND ATTEMPTS TO MAXIMIZE THE OVERALL MILL PROFIT.

289. PARKS, G. M. 1964. DEVELOPMENT AND APPLICATION OF A MODEL FOR SUPPRESSION OF FOREST FIRES. MANAGE. SCI., 1W(4):760-766. EQUATIONS TO MINIMIZE TOTAL COSTS OF FIRE SUPPRESSION AND FIRE DAMAGE (DERIVED FROM A SIMPLE FIRE-GROWTH MODEL USING D.R. TECHNIQUES) WERE APPLIED TO DATA FROM 139 FIRES IN THE PIUMAS NATIONAL FOREST, CALIFORNIA. RESULTS INDICATE THAT LARGER FIRE CREWS WOULD REDUCE TOTAL FIRE COSTS, AND THAT 75 PERCENT OF ALL THE FIRES WERE UNDERMANNED.
290. PATRONE, G. 1965. PROGRAMMAZIONE LINEARE IN SELVICOLTURA. (LINEAR PROGRAMMING IN FORESTRY.) 160 PP. FLORENCE: BRUNO COPPINI AND CO. (IN ITALIAN.) CHAPTERS ON: INFORMATION IN WORK STUDIES, MATHEMATICAL THEORY OF LP, ECONOMIC SIGNIFICANCE OF LP, GRAPHIC REPRESENTATION OF PROBLEMS WITH TWO CONSTRAINTS, THE SIMPLEX METHOD OF CALCULATION, THE GEOMETRIC SIGNIFICANCE OF THE SIMPLEX METHOD, THE PROBLEM OF DISTRIBUTION, AND PROBLEMS OF LP IN FORESTRY,
291. PAULL, A. E. 1956. LINEAR PROGRAMMING: A KEY TO OPTIMUM NEWSPRINT PRODUCTION. PULP AND PAPER MAG. CAN. 57(4):145-150. TWO APPLICATIONS OF LINEAR PROGRAMMING IN THE PULP AND PAPER INDUSTRY ARE DISCUSSED: TRANSPORTATION SCHEDULING AND TRIM SCHEDULING. BOTH OF THESE APPLICATIONS HAVE BEEN SUCCESSFULLY PUT TO USE AT ABITIBI. TRANSPORTATION SCHEDULING CONCERNS ASSIGNING VARIOUS ORDERS TO SEVERAL MILLS SO AS TO MINIMIZE THE TOTAL COMPANY FREIGHT BILL. TRIM SCHEDULING IS CONCERNED WITH MACHINE ASSIGNMENTS AND COMBINATIONS TO MINIMIZE OVERALL TRIM LOSS.
292. PAULL, A. E., AND J. R. WALTER. 1955. THE TRIM PROBLEM: APPLICATION OF LINEAR PROGRAMMING TO THE MANUFACTURE OF NEWSPRINT PAPER. ECONOMETRICA 23(3):336. ABITIBI MANUFACTURES ROLLS OF NEWSPRINT PAPER TO MEET CUSTOMERS' SPECIFICATIONS WITH REGARD TO WIDTH AND DIAMETER. IN CUTTING THESE ROLLS FROM LARGER REELS OF PAPER, TRIM LOSSES ARE INCURRED. THIS STUDY DESCRIBES AN APPLICATION OF LINEAR PROGRAMMING METHODS TO THE

REDUCTION OF TOTAL TRIM LOSS INCURRED BY SIX OF
THEIR PAPER MACHINES.

293. PAYANDEH, R., 1968. A COMPUTER SIMULATION STUDY OF THE RELATIVE EFFICIENCY OF SEVERAL FOREST SAMPLING TECHNIQUES AS INFLUENCED BY THE SPATIAL DISTRIBUTION OF TREES FOUND IN FIVE MAJOR FOREST TYPES OF THE PACIFIC NORTHWEST. DISS. ABSTR. 28B(11):4371-4372. A STUDY TO DETERMINE THE RELATIVE EFFICIENCY OF SYSTEMATIC, STRATIFIED, AND SIMPLE RANDOM SAMPLING FOR ESTIMATING CROWN AREA AND TREE FREQUENCY. ALSO, AN EVALUATION WAS MADE OF SOME COMMON METHODS OF ESTIMATING SPATIAL DISTRIBUTION COEFFICIENTS, AND TO DETERMINE THE EFFECT OF SPATIAL DISTRIBUTION ON THE RELATIVE EFFICIENCY OF TWO-DIMENSIONAL SYSTEMATIC SAMPLING. THE BASIC DATA (FROM AERIAL PHOTOS) WERE THE LOCATION AND SIZE OF EACH TREE CROWN.
294. PEARSE, P. H., AND S. SYDNEYSMITH, 1966. METHODS FOR ALLOCATING LOGS AMONG SEVERAL UTILIZATION PROCESSES. FOREST PROD. J. 16(9):87-98. LINEAR PROGRAMMING IS USED FOR ASSIGNING LOGS AND INTERMEDIATE PRODUCTS TO USES AS LUMBER, VENEER, CHIPS, PULP, PLYWOOD, AND LOG FUEL FOR MAXIMIZING THE NET ECONOMIC VALUE OF OUTPUT. THE UTILIZATION OF THE 1962 LOG SUPPLY IN BRITISH COLUMBIA IS COMPARED TO THE OPTIMUM UTILIZATION OBTAINED BY SOLUTION OF THE LP MODEL.
295. PENICK, E. B., JR. 1966. TURNING FOR PROFIT: AN APPLICATION OF OPERATIONS RESEARCH TECHNIQUES TO A WOOD-TURNING PLANT. FOREST PROD. 16(1):24-27. LINEAR PROGRAMMING WAS APPLIED TO THE OPERATIONS OF A SMALL FIRM WHICH MAKES WOOD TURNINGS BY CONTRACT FOR A BROAD RANGE OF CUSTOMERS. THE LP SOLUTION HELPED THE PLANT MANAGER ELIMINATE PRODUCTION BOTTLE-NECKS, GAVE HIM GUIDELINES FOR COMPETITIVE BIDDING, AND TOLD HIM WHICH ORDERS WOULD GIVE THE MOST PROFIT.
296. PENICK, E. B., JR., 1968. LINEAR PROGRAMMING: APPLICATION TO MACHINE LOADING IN A FURNITURE PLANT. FOREST PROD. J. 18(2):29-34. THE PROCESS FOUND THE COMBINATION OF FURNITURE PIECES THAT MOST NEARLY OPTIMIZED LOADS ON AVAILABLE MACHINERY. SUCH PROGRAMMING SHOULD LEAD TO MORE EFFECTIVE USE OF MACHINE AND LABOR RESOURCES AND THUS REDUCE PRODUCTION COSTS.
297. PENICK, E. B., JR., AND G. E. FRICK, 1965. APPLICATION OF AN OPERATIONS RESEARCH TECHNIQUE TO A WOOD-TURNING PLANT. UNIV. OF NEW HAMPSHIRE.

AGR. EXP. STA. Mimeo. 38, 17 pp. AN APPLICATION OF LINEAR PROGRAMMING TO THE PROBLEM OF PRODUCT SELECTION IN A SMALL WOOD-TURNING FIRM. THE PROBLEM DEALS WITH MAKING THE MOST EFFICIENT USE OF LIMITED LATHE TIME THROUGH SELECTION OF THE MOST PROFITABLE COMBINATION OF PRODUCTS.

298. PETROVSKY, V. S. 1963. (ALGORITHMS FOR PROGRAMMING THE CROSS-CUTTING OF TREE-LENGTH LOGS.) LESN. PROM. (7):10-12. (IN RUSSIAN.) THE OPTIMUM SCHEDULE FOR CROSS-CUTTING EACH STEM IN A SAWMILL SHOULD SECURE (1) THE MAXIMUM YIELD FROM LOGS IN TERMS OF MONEY AT PREVAILING PRICES, (2) THE MAXIMUM YIELD FROM LOGS BY VOLUME, (3) THE MAXIMUM YIELD OF THE MAIN ASSORTMENT, E.G. SAWTimmer, AND (4) THE MAXIMUM VOLUME OF CYLINDRICAL LOGS. ALGORITHMS, USING SPECIES, STEM QUALITY, STEM LENGTH, STEM DIAMETER, AND ROT DIAMETER AT BUTT, ARE DEVELOPED FOR EACH OF THESE REQUIREMENTS WITH AN EXPLANATION OF THEIR MATHEMATICAL DERIVATION, AND A COMBINED MAXIMIZING ALGORITHM FOR OPTIMUM CROSCUTTING IS PRESENTED.
299. PETROVSKY, V. S. 1964. (CONSTRUCTION OF AN AUTOMATIC OPTIMIZATION SYSTEM FOR CROSS-CUTTING STEMS, WITH THE AIM OF USING DIGITAL COMPUTERS TO CONTROL THE BREAKING DOWN OF TREE-LENGTH LOGS.) LESN. Z. ARHANGEL'SK 7(4):147-157. (IN RUSSIAN WITH RUSSIAN SUMMARY.) A DETAILED MATHEMATICAL EXPOSITION.
300. PETROVSKY, V. S. 1968. (ALGORITHMS FOR THE CROSS-CUTTING OF STEMS INTO SAWLOGS, DESIGNED TO MAXIMIZE THE VOLUME YIELD OF EDGED TIMBER.) LESN. Z. ARHANGEL'SK 11(4):122-126. (IN RUSSIAN.) AN ALGORITHM IS DEVELOPED FOR OPTIMIZING YIELD IN THE FIRST STAGE OF LOG BREAKDOWN. COMPUTER CALCULATIONS USING A PROGRAM WRITTEN ON THE BASIS OF THIS ALGORITHM HAVE SHOWN THAT OPTIMIZATION CAN PRODUCE A 2 PERCENT INCREASE IN YIELD.
301. PHELPS, R. B. 1966. THE APPLICATION OF A LINEAR PROGRAMMING TECHNIQUE TO THE PROCUREMENT OF PULPWOOD. M.S. THESIS, NC STATE COLL., RALEIGH. LINEAR PROGRAMMING IS USED TO CALCULATE A LEAST COST PROGRAM FOR THE PURCHASE OF PULPWOOD BY AN INDIVIDUAL PULPMILL.
302. PLEINES, W. F. 1967. (LINEAR PROGRAMMING OF YIELD AND FELLING PLANS.) SCHWEIZ. Z. FORSTW. 118(9):551-560. (IN FRENCH WITH GERMAN SUMMARY.) LINEAR PROGRAMMING IS USED TO DETERMINE THE ANNUAL CUT (IN PUHE, EVEN-AGED SPRUCE) OVER A 10-YEAR

PERIOD THAT WOULD MAXIMIZE NET REVENUE. THE RESULTS INCLUDE THE DISTRIBUTION OF FINAL FELLINGS AND THINNINGS OVER THE VARIOUS FICTITIOUS SITE AND AGE CLASSES, AND THE EFFECT OF MONETARY AND OTHER RESTRAINTS.

INTS.

303. POPOVIC, U. D. 1965. APPLICATION OF LINEAR PROGRAMMING TO THE PROBLEMS OF FOREST ECONOMICS. SUMARSTV 18(3-5):121-133. (IN SERBO-CROATIAN, SUMMARY IN ENGLISH.) IN CONTINUATION OF HIS STUDY, THE AUTHOR EXPLAINS THE GENERAL TECHNIQUE OF CALCULATING BY THE SIMPLEX METHOD. INSTRUCTIONS FOR PREPARING THE SIMPLEX TABLES, CALCULATING THE VALUES IN SUCH TABLES, AND THEIR EXPLANATIONS ARE GIVEN. AN EXAMPLE OF CALCULATING THE OPTIMAL NUMBER OF PRODUCTS (TABLES AND CHAIRS) FROM THE FIXED MATERIAL IN A WORKSHOP WHILE SIMULTANEOUSLY ATTAINING THE HIGHEST PROFIT IS INCLUDED.
304. POULIOT, J. M. 1966. THE APPLICABILITY OF LINEAR PROGRAMMING TO A TIMBER-ALLOCATION PROBLEM. M.S. THESIS, STATE UNIV. N.Y. COLL. FORESTRY, SYRACUSE. THE PURPOSE OF THIS STUDY IS TO EXPLORE THE APPLICATION OF THE TRANSPORTATION MODEL OF LINEAR PROGRAMMING TO THE TIMBER-ALLOCATION PROBLEM. THE STUDY APPLIES THE TECHNIQUE TO A HYPOTHETICAL PROBLEM AND RELATES THE RESULTS TO THE ACTUAL PROBLEM THAT EXISTS IN QUEBEC. THE MODEL CONSIDERS THE LOGGING AS WELL AS THE TRANSPORTATION OF TIMBER FROM DIFFERENT SOURCES TO DIFFERENT MILLS.
305. PRUDIC, Z. 1962. (LINEAR PROGRAMMING AND ITS USE FOR DETERMINING PRODUCTION (ECONOMIC) OBJECTIVES.) LESNICTVI 8(4):251-262. PRAGUE. (CZECHOSLOVAKIAN, RUSSIAN, WITH SUMMARY IN FRENCH.) NO ENGLISH SUMMARY AVAILABLE.
306. PRUDIC, Z. 1968. (FORESTRY AND GAME THEORY.) LESNICKA PRACE 47(3):121-125. (IN CZECHOSLOVAKIAN.) NO ENGLISH SUMMARY IS AVAILABLE.
307. RAIFFA, H., AND R. SCHLAIFER. 1961. APPLIED STATISTICAL DECISION THEORY. 356 PP. CAMBRIDGE, MASS.: HARVARD UNIV., DIV. PES., GRAD. SCHOOL BUS. ADMIN. CONTENTS INCLUDE: GENERAL THEORY OF DECISIONS, SUFFICIENT STATISTICS AND NONINFORMATIVE STOPPING, CONJUGATE PRIOR DISTRIBUTIONS, LINEAR TERMINAL ANALYSIS, SELECTION OF THE BEST OF SEVERAL PROCESSES, UNIVARIATE

NORMALIZED MASS AND DENSITY FUNCTIONS,
MULTIVARIATE NORMALIZED DENSITY FUNCTIONS,
BERNOULLI PROCESS, POTSSON PROCESS, NORMAL
PROCESSES, AND NORMAL REGRESSION PROCESS.

308. RAMSING, K. D. 1965. A LINEAR PROGRAMMING MODEL FOR THE ALLOCATION OF LOGS FOR THE MANUFACTURE OF AN OPTIMUM PLYWOOD MIX. D.B.A. THESIS, UNIV. OREG., PORTLAND. RESULTS FROM THE LINEAR PROGRAMMING SOLUTION: QUANTITY OF LOGS BY GRADE TO BE MANUFACTURED INTO EACH VENEER THICKNESS; QUANTITY OF EACH KIND OF PLYWOOD PANEL TO BE MANUFACTURED IN ORDER TO MAXIMIZE PROFIT.
309. RAMSING, K. D. 1966. HOW THE CRITICAL PATH METHOD CAN ASSIST ROAD CONSTRUCTION - PART I. FOREST IND. 93(13):66-69. THE CRITICAL PATH METHOD (CPM) COORDINATES ACTIVITIES INVOLVED IN A SINGLE PROJECT. THE CONSTRUCTION OF LOGGING ROADS PROVIDES A GOOD APPLICATION FOR CPM.
310. RAMSING, K. D. 1967. HOW THE CRITICAL PATH METHOD CAN ASSIST ROAD CONSTRUCTION - PART II. FOREST IND. 94(1):180-183. A CONTINUATION OF THE PREVIOUS CITATION.
311. RAMSING, K. D. 1968. LINEAR PROGRAMMING FOR THE PLYWOOD MIX PROBLEM. FOREST PROD. J. 18(4):98-101. TWO VENEER-TO-PLYWOOD PROBLEMS ARE SOLVED WITH LINEAR PROGRAMMING TECHNIQUES. A SIMPLIFIED VERSION IS APPROACHED BY GRAPHICAL SOLUTION AND A MORE COMPLICATED PROBLEM IS SOLVED BY THE SIMPLEX APPROACH. THE APPLICATION OF LP TO NEW PRODUCT DEVELOPMENT IS ALSO DISCUSSED.
312. RAMSING, K. D. 1969. HOW THE CRITICAL PATH METHOD CAN ASSIST LOGGING ROAD CONSTRUCTION. PHILLIP. LUMBERMAN 15(11-12):34, 35, 37, 28-31. THE MATERIAL IN TWO PREVIOUS CITATIONS (RAMSING, 1966 AND 1967) IS PRESENTED IN THESE ARTICLES.
313. RANDEL, W. C. 1964. LINEAR PROGRAMMING IN A SMALL FOREST PRODUCTS FIRM. DISS. ABSTR. 25(3):1468. THE SIMPLEX METHOD OF LINEAR PROGRAMMING IS USED TO DETERMINE AN OPTIMUM PRODUCTION SCHEDULE FOR A SMALL FIRM MAKING A LIMITED VARIETY OF GOODS. DETAILED TIME AND COST STUDIES WERE MADE OF THE PROCESSES, MATERIALS, AND PRODUCTS INVOLVED. THREE ALTERNATIVE OPTIMUM SOLUTIONS ARE PRESENTED, EACH REPRESENTING A DIFFERENT SET OF CONDITIONS IN FORCE AT THE TIME OF SOLUTION.
314. REIMER, D. R. 1969. DEVELOPMENT OF A LEONTIEF

INPUT-OUTPUT MODEL AND ITS APPLICATION IN THE ANALYSIS OF THE ECONOMIC IMPACT OF A NEW FOREST INDUSTRY ON THE ECONOMIC GROWTH AND DEVELOPMENT OF AN UNDERDEVELOPED MICRO-REGION IN SOUTHERN INDIANA. PH.D. DISS., PURDUE UNIV., LAFAYETTE, IND. THE STUDY ATTEMPTED TO DETERMINE THE ECONOMIC CONTRIBUTION OF A NEWLY ESTABLISHED PARTICLEBOARD PLANT AT EVANSTON, INDIANA, TO THE LOCAL ECONOMY. A LEONTIEF-TYPE INPUT-OUTPUT MODEL WAS CONSTRUCTED FOR EVALUATING THE PARTICLEBOARD PLANT AND THREE OTHER WOOD-USING INDUSTRIES THAT WERE CONSIDERING ESTABLISHMENT WITHIN THE LOCAL AREA. INDICATIONS WERE THAT AN INTEGRATED SAWMILL-VENEER-PLYWOOD COMPLEX WOULD PROVIDE GREATER ECONOMIC BENEFITS THAN EITHER THE PARTICLEBOARD PLANT, A PULP MILL, OR A PULP AND PAPER MILL.

315. REYNOLDS, H. W. 1970. SAWMILL SIMULATION: DATA INSTRUCTIONS AND COMPUTER PROGRAMS. USDA FOREST SERV. NE FOREST EXP. STA. RES. PAPER NE-152, 41 PP., ILLUS. UPPER DARBY, PA. INSTRUCTIONS AND COMPUTER PROGRAMS FOR COMPUTER PROGRAM DEFECT TO SIMULATE SAWING LOGS INTO BOARDS. LOG SAMPLES ARE SAWED, AND THE TYPE AND LOCATION OF ALL DEFECTS ARE ENCODED INTO THE COMPUTER. THE LOGS ARE IN EFFECT REASSEMBLED WITHIN THE COMPUTER AND CAN BE SAWED REPEATEDLY WITH DIFFERENT SAWING PATTERNS. THE PROGRAM SHOWS HOW DEFECTS APPEAR ON EACH NEW BOARD FOR EACH NEW SAWING PATTERN. THE INSTRUCTIONS INCLUDE HOW TO USE COMPUTER PROGRAM YIELD TO SIMULATE THE RIPPING AND TRIMMING OF BOARDS GENERATED BY PROGRAM DEFECT.
316. RIIKONEN, R., AND J. RYHANEN. 1965. (ELECTRONIC DATA-PROCESSING IN THE OPTIMIZATION OF SAWMILL PRODUCTION.) PAP. JA PUU 47(9):497-502. (IN FINNISH WITH FINNISH AND ENGLISH SUMMARIES.) A COMPUTER PROGRAM IS DESCRIBED THAT SIMULATED DIFFERENT ALTERNATIVES IN SAWING A LOG, CHOOSING THE ONE THAT WILL GIVE THE MOST PROFITABLE ECONOMIC RESULT. ACCOUNT IS TAKEN OF VARIATIONS IN QUALITY BY CALCULATING THE RESULTS GIVEN BY BOTH A GOOD AND A POOR QUALITY LOG. THE PROGRAM IS INTENDED PRIMARILY AS A HELP IN SELECTING THE BEST INCH-CLASS LIMITS FOR SAWLOG ASSORTMENT AND IN CHOICE OF SAW SPACING.
317. RILEY, V. 1953. AN ANNOTATED BIBLIOGRAPHY ON OPERATIONS RESEARCH. CHEVY CHASE, MD.: OPER. RES. OFFICE, JOHNS HOPKINS UNIV. THIS VOLUME CONTAINS THE FIRST FOUR SECTIONS OF A COMPLETE ANNOTATED BIBLIOGRAPHY OF OPERATIONS RESEARCH.

OPERATIONS RESEARCH IS DEFINED BY THE AUTHOR AS THE SCIENCE THAT PROVIDES ADMINISTRATORS WITH A SCIENTIFIC EVALUATION OF ALTERNATIVE COURSES OF ACTION AND A QUANTITATIVE BASIS FOR DECISION. THESE FOUR SECTIONS INCLUDE THE LITERATURE DEALING WITH HISTORY AND METHODOLOGY, MILITARY APPLICATIONS, INDUSTRIAL APPLICATIONS, AND GOVERNMENT PLANNING USING OPERATIONS RESEARCH.

318. RILEY, V., AND J. P. YOUNG. 1957. BIBLIOGRAPHY ON WAR GAMING. CHEVY CHASE, MD.: OPER. RES. OFFICE, JOHNS HOPKINS UNIV. IT IS THE PURPOSE OF THIS WORK TO PRESENT REFERENCES TO HISTORICAL AND CONTEMPORARY EFFORTS THAT HAVE BEEN INSTRUMENTAL IN THE DEVELOPMENT OF THE TECHNIQUES OF WAR GAMING. WAR GAMES ARE DEFINED AS IMAGINARY MILITARY OPERATIONS. ALL OF THE EARLY WAR GAMES ARE LISTED IN CHRONOLOGICAL ORDER WITHIN THEIR RESPECTIVE CATEGORIES. THE MODERN WAR GAMES ARE CLASSIFIED INTO THEORETICAL GAMES THAT INCLUDE MATHEMATICAL MODELS AND GAMES WITH NO SPECIFIC MILITARY APPLICATION; AND MILITARY GAMES DEVELOPED PRIMARILY FOR THE SOLUTION OF MILITARY PROBLEMS INVOLVING LAND, SEA, OR AIR WARFARE.
319. RIPLEY, T. H., AND D. O. YANDLE. 1969. A SYSTEMS ANALYSIS-ECOLOGICAL CONTROL APPROACH TO MULTIRESOURCE FOREST MANAGEMENT. J. FOREST, 67(11):806-809. A GENERAL ARTICLE OUTLINING AN APPROACH FOR CONSIDERING MULTI-PRODUCT AND SERVICE ALTERNATIVES IN MANAGING A FOREST PROPERTY. THE USE OF LINEAR PROGRAMMING, DYNAMIC LINEAR PROGRAMMING, AND DYNAMIC PROGRAMMING IN RESOURCE MANAGEMENT IS BRIEFLY DISCUSSED.
320. RISVAND, J. 1970. (ECONOMIC ANALYSIS OF CUTTING PROGRAMS APPLYING DYNAMIC PROGRAMMING.) NORSKE SKOGFORSOKSV. MEDD. 28(1), 110 PP. (IN NORWEGIAN WITH SUMMARY IN ENGLISH.) DYNAMIC PROGRAMMING WAS USED AS THE BASIS FOR CONSTRUCTING AN ECONOMIC MODEL TO MANAGE A GIVEN FOREST STAND. THE PROFITABILITY CRITERION (MAXIMUM PRESENT VALUE) WAS THE ONLY ELEMENT OF PURPOSE. THE STATE OF THE FOREST STAND IS DESCRIBED IN TERMS OF THE VOLUME PER HECTARE AND MEAN DIAMETER. THE DEVELOPMENT OF THE STAND IS THEN ESTIMATED FROM A GIVEN INITIAL STATE.
321. RISVAND, J., AND K. HOBBELSTAD. 1968. (MODERN PLANNING METHODS.) LANDBRUKETS ARBOK, SKOGBRUK, 21 PP. (IN NORWEGIAN.) A GENERAL REVIEW OF OPERATIONS RESEARCH METHODS WITH SPECIAL REFERENCE TO LINEAR PROGRAMMING.

322. ROHDE, F. V. 1957. BIBLIOGRAPHY ON LINEAR PROGRAMMING. OPER. RES. 5(1):45-62. THIS BIBLIOGRAPHIC ESSAY CONTAINS 266 REFERENCES AND COVERS THE DEVELOPMENT OF LINEAR PROGRAMMING AND ITS VARIOUS APPROACHES AND PROBLEMS.
323. RONNUO, C. A. 1963. (THE PLANNING OF ROAD NETWORKS -- A PROBLEM OF STOCK SIZE DETERMINATION BY OPERATIONAL ANALYSIS.) SVENSKA SKOGSV FOREN. TIDSKR. 61(4):383-389. (IN SWEDISH.) TECHNIQUES OF STOCK SIZE DETERMINATION ARE APPLIED TO OPTIMIZE QUANTITIES OF CORDWOOD PER LANDING (BEFORE MACHINE BARKING AND SELLING) FOR THE PURPOSE OF DEMONSTRATING THAT THE PLANNING OF OPTIMUM-DENSITY ROAD NETWORKS MAY BE SOLVED BY THE SAME MATHEMATICAL APPROACH.
324. ROW, C., C. FASICK, AND S. GIITTENBERG. 1965. IMPROVING SAWMILL PROFITS THROUGH OPERATIONS RESEARCH. USDA FOREST SERV. SOUTH. FOREST EXP. STA. RES. PAPER SO-20. 26 PP. NEW ORLEANS, LA. THE OPERATIONS OF A HIGH-SPEED SOUTHERN PINE SAWMILL ARE ANALYZED IN FOUR PARTS: (1) A YIELD ANALYSIS OF LOGS SAWN, (2) TIMES REQUIRED ON EACH MACHINE, (3) ESTABLISHING CONSTRAINTS ON INPUT, TIMES, AND SALES, AND (4) ANALYSIS OF ALL THESE DATA BY LINEAR PROGRAMMING. RESULTS ARE TABULATED AND IT IS SUGGESTED THAT THIS METHOD HAS WIDE APPLICATION IN SAWMILL OPERATION.
325. RUPRICH, J., AND J. KORINEK. 1968. (AN ANALYSIS OF THE LABORIOUSNESS OF APPROXIMATION METHODS IN THE SOLUTION OF THE TRANSPORT PROBLEM IN FORESTRY.) LESN. CAS. 14(5):405-420. THE VOGEL APPROXIMATION TO LINEAR PROGRAMMING IS COMPARED TO THREE OTHER TECHNIQUES FOR SOLVING PROBLEMS OF TIMBER REMOVAL. THE VOGEL APPROXIMATION METHOD WAS BETTER SUITED FOR LARGER PROBLEMS HAVING MATRICES ON THE ORDER OF 50 X 20.
326. RYKUNIN, S. N. 1966. THE LINEAR PROGRAMMING METHOD AND ITS USE IN PLANNING THE SAWING OF LOGS. TRANSL. COMMONW. SCI. INDUS. RES. ORGAN. AUST. 7747. 5 PP. (TRANSL. BY J. A. COLLINS FROM LESN. PROM. 7, PP. 25-27, 1965.) THE USE OF LINEAR PROGRAMMING IN PLANNING THE OPTIMUM OR NEAR-OPTIMUM CONVERSION OF ROUNDWOOD TO LUMBER IS DISCUSSED.
327. RYTI, N., AND M. KIRJOSNIEMI. 1968. (SEARCH FOR AN OPTIMUM PROGRAM FOR THE WOODWORKING INDUSTRY WHEN WOOD RAW MATERIAL IS A LIMITING FACTOR.) PAP. JA PUU. 50(3):109-116. HELSINKI. (IN FINNISH WITH

ENGLISH SUMMARY,) LINEAR PROGRAMMING IS APPLIED TO A WOODWORKING INDUSTRY FACED WITH A LIMITED SUPPLY OF WOOD AS THE MAJOR CONSTRAINT.

328. SAATY, T. L. 1961. ELEMENTS OF QUEUING THEORY. 440 PP., ILLUS. NEW YORK: MCGRAW HILL BOOK CO. PRESENTS A VARIETY OF QUEUING RAMIFICATIONS, METHODS OF TREATMENT. MOST OF THE FUNDAMENTAL IDEAS OF QUEUES ARE DISCUSSED AND DEVELOPED, AS ARE MANY APPLICATIONS, IN ADDITION TO A DISCUSSION OF BOTH POISSON AND NON-POISSON QUEUES WITH DIFFERENT QUEUING DISCIPLINES.
329. SADLER, R. R. 1970. BUFFER STRIPS, A POSSIBLE APPLICATION OF DECISION THEORY. U.S. DEP. INTERIOR BUR. LAND MANAGE. TECH. NOTE 6512, 11 PP. DECISION THEORY IS USED IN WEIGHING FISHERY VERSUS TIMBER VALUES.
330. SAJECHECHNIKOV, V. G., AND P. I. GORYSHIN. 1968. APPLICATION OF METHODS OF LINEAR PROGRAMMING. CENT. SCI. RES. INST., 23 PP. MOSCOW. ECONOMIC USE OF LOG TRUCKS ON STATE-OWNED FORESTS.
331. SAKAMOTO, T. 1966. (STUDY ON THE RISK PROGRAMMING OF FORESTRY MANAGEMENT,) KYUSHU UNIV. FOREST. BULL. 40;91-239. (IN JAPANESE WITH ENGLISH SUMMARY.) THE PRESENTATION OF A PROGRAMMING METHOD SUITED TO LONG-RUN FOREST-MANAGEMENT PLANNING THAT CONSIDERS RISK AND UNCERTAINTY, OPPORTUNITY COSTS OF INVESTMENT, AND NET PROFIT. THE MODEL LEADS TO RESULTS SIGNIFICANTLY DIFFERENT FROM THE TRADITIONAL METHODS.
332. SAMPSON, G. R. 1969. THE MAJOR DISADVANTAGES AND ADVANTAGES OF USING OPERATIONS RESEARCH AS A MANAGEMENT INFORMATION TECHNIQUE. OPER. RES. APPL. TO SAWMILLS PROC.:51-55. UNIV. OF GEORGIA, ATHENS. THIS PAPER PRESENTS MAJOR DISADVANTAGES OF THE APPLICATION OF OPERATIONS RESEARCH TO A SAWMILL AND REVIEWS SOME MINOR PROBLEMS. MAJOR AND MINOR ADVANTAGES OF USING THIS MANAGEMENT INFORMATION TECHNIQUE ARE ALSO SUMMARIZED.
333. SAMPSON, G. R. 1969. A REVIEW OF OPERATIONS RESEARCH IN THE FOREST INDUSTRY. OPER. RES. APPL. TO SAWMILLS PROC.:5-11. UNIV. GEORGIA, ATHENS. THE CONCEPTION OF OPERATIONS RESEARCH IS DESCRIBED AND A REVIEW OF HOW THESE METHODS HAVE DEVELOPED IN FOREST MANAGEMENT, HARVESTING, PLYWOOD MANUFACTURING, SAWMILL OPERATIONS, AND MULTI-PLANT FACILITIES IS PRESENTED.

334. SAMPSON, G. R., AND C. A. FASICK. 1970. OPERATIONS RESEARCH APPLICATION IN LUMBER PRODUCTION. FOREST PROD. J. 20(5):12-16. AN OPERATIONS RESEARCH APPROACH IS USED TO ANALYZE THE OPERATION OF A SOUTHERN PINE SAWMILL. A LINEAR PROGRAMMING MODEL IS USED TO SIMULATE OPERATIONS OF THE MILL. THE ANALYSIS INCLUDES THE EFFECTS OF DOWNTIME ON NET REVENUE, THE EFFECTS OF DIFFERENT LEVELS OF INPUT ON NET REVENUE, AND RECOMMENDATIONS FOR PROFIT MAXIMIZATION.
335. SCHALEK, M. 1965. (APPLICATION OF LINEAR PROGRAMMING IN THE SOLUTION OF TRANSPORTATION OF LOGS.) LESNICKA PRACE 44(9):407-410. (IN CZECHOSLOVAKIAN.) NO ENGLISH SUMMARY IS AVAILABLE.
336. SCHLAIFER, R. 1959. PROBABILITY AND STATISTICS FOR BUSINESS DECISIONS: AN INTRODUCTION TO MANAGERIAL ECONOMICS UNDER UNCERTAINTY. 732 PP. NEW YORK: McGRAW-HILL BOOK CO. A TEXT AND GENERAL SURVEY OF BAYESIAN DECISION THEORY. A DISCUSSION OF THE BASIC PROBABILISTIC PROCESSES THAT PLAY A CENTRAL ROLE IN FREQUENTIST APPROACHES (BERNOULLI PROCESS, BINOMIAL, AND PASCAL PROBABILITIES, POISSON PROCESS, ETC.). RESULTS ARE USED IN A BAYESIAN FRAMEWORK WITH CONSIDERABLE EMPHASIS ON PRIOR PROBABILITIES.
337. SCHMIDT, J. W., JR., W. D. TORLANE, J. BYRD, AND M. R. FEDORKO. 1970. FEASIBILITY STUDY ON THE RETRIEVAL AND USE OF PRIMARY WOOD RESIDUE. WEST VA. UNIV. ENG. EXP. STA. RPT. 11, 250 PP. MORGANTOWN A COMPUTER SIMULATION MODEL IS DISCUSSED AND PRESENTED (FLOW CHART AND LISTING ARE GIVEN). THIS MODEL ANALYZES THE FEASIBILITY OF REMOVING AND UTILIZING WOOD WASTE LEFT IN THE FOREST IN THE APPALACHIAN REGION AFTER COMPLETION OF PRIMARY LOGGING OPERATIONS. RESULTS INDICATE THAT AT THE PRESENT TIME IT IS UNLIKELY THAT PRIMARY WOOD WASTE CAN BE ECONOMICALLY RETRIEVED FROM THE STUMP AREA.
338. SCHOPFER, W. 1967. (A SAMPLING SIMULATOR FOR RESEARCH AND TEACHING.) ALLG. FORST U. JAGDZTG, 138(12):267-273. (GERMAN WITH SUMMARIES IN GERMAN, ENGLISH, AND FRENCH.) A COMPUTER PROGRAM "STIPSI" (FROM GERMAN "STICHPROBENSIMULATOR"), IS NOW BEING DEVELOPED AT THE BADEN-WURTTEMBERG FOREST RESEARCH INSTITUTE. IT IS WRITTEN IN FORTRAN IV FOR AN IBM 7040 AND AT THE PRESENT STAGE, COVERS VARIOUS METHODS OF SAMPLING FOR BASAL AREA AND STEM NUMBERS.

339. SCHREUDER, G. F. 1968. OPTIMAL FOREST INVESTMENT DECISIONS THROUGH DYNAMIC PROGRAMMING. PH.D. DISS. YALE UNIV., NEW HAVEN, CONN. THE ENTIRE PRODUCTION PROCESS FROM TREE SEEDLING TO FINAL PRODUCT IS VIEWED AS A STRING OF REVENUE AND COST FUNCTIONS, WHICH TOGETHER FORM THE OBJECTIVE FUNCTION TO BE MAXIMIZED.
340. SCHREUDER, G. F. 1968. OPTIMAL FOREST INVESTMENT DECISIONS THROUGH DYNAMIC PROGRAMMING. YALE UNIV. SCHOOL FORESTRY BULL. 72, 70 PP. SEE PREVIOUS CITATION.
341. SCHULTZ, R. D. 1964. DECISION MAKING IN A WILDLAND FIRE GAME. PH.D. DISS., UNIV. CALIF., BERKELEY. A WILDLAND FIRE GAME SIMULATION IS DEVELOPED FOR USE IN MEASURING THE EFFECTS OF ALTERNATIVE FIRE-DEFENSE SYSTEMS. THE MODEL IS A MODIFICATION OF THE MILITARY WAR GAME, AND PERMITS DIFFERENT FIRE MANAGERS TO BE CONFRONTED BY THE SAME FIRE SITUATION IN A LABORATORY ENVIRONMENT. THE SIMULATOR COMBINES VARIOUS INPUTS TO OBTAIN THE RESULTS OF CONFLICT BETWEEN THE FIRE AND THE FIRE-DEFENSE SYSTEM.
342. SCHULTZ, R. D. 1966. GAME SIMULATION AND WILD LAND FIRE. J. FOREST. 64(12):791-800. THE USE OF GAME SIMULATION (MODELED ON THE MILITARY WAR GAME) FOR EVALUATION OF ALTERNATIVE FIRE-SUPPRESSION DEFENSE SYSTEMS BY DIFFERENT MANAGEMENT TEAMS IN A POTENTIALLY CATASTROPHIC FIRE IN CALIFORNIA WILD LANDS IS DESCRIBED. POSSIBLE RELATIONSHIPS BETWEEN SIMULATION RESULTS AND POLICY-MAKING ARE OUTLINED.
343. SCHWEITZER, DENNIS L. 1970. THE IMPACT OF ESTIMATION ERRORS ON EVALUATIONS OF TIMBER PRODUCTION OPPORTUNITIES. USDA FOREST SERV. N. CENTRAL FOREST EXP. STA. RES. PAP. NC-43, 18 PP., ILLUS. ST. PAUL, MINN. ERRORS IN ESTIMATING COSTS AND RETURNS, THE TIMING OF HARVESTS, AND THE COST OF USING FUNDS CAN GREATLY AFFECT THE APPARENT DESIRABILITY OF INVESTMENTS IN TIMBER PRODUCTION. PARTIAL DERIVATIVES ARE USED IN SENSITIVITY ANALYSES TO MEASURE THE IMPACTS OF THESE ERRORS ON THE PREDICTED PRESENT NET WORTH OF POTENTIAL INVESTMENTS IN TIMBER PRODUCTION. GRAPHS THAT ILLUSTRATE THE IMPACT OF EACH TYPE OF ESTIMATION ERROR AND A COMPUTER ROUTINE TO PERFORM THE NECESSARY COMPUTATIONS ARE INCLUDED.
344. SEALE, R. H. 1966. FORESTRY AS A SYSTEM. PH. D. DISS. STATE UNIV. N.Y., COLL. FORESTRY, SYRACUSE,

THE FUNCTIONAL CONCEPT OF A SYSTEM IS STRESSED. FORESTRY IS POSTULATED AS A SYSTEM THAT COMBINES FOREST RESOURCES WITH OTHERS, TRANSFORMS THEM SO AS TO CREATE OR ENHANCE UTILITY, AND YIELDS GOODS AND SERVICES. THE ECOSYSTEM CONCEPT WAS EMPLOYED AS A MEANS BOTH OF ILLUSTRATING THE SYSTEM CONCEPT AND OF DEMONSTRATING THE SYSTEM NATURE OF CERTAIN PHYSICAL-BIOLGICAL COMPONENTS OF FORESTRY. THE MANAGERIAL SUBSYSTEM THAT GOVERNS THE WHOLE FORESTRY SYSTEM WAS ALSO ADDED.

345. SHAFER, E. L., JR. 1970. THE NAME OF THE GAME IS RECREATION RESEARCH. ENVIRON. EDUC. 2(1):30-34. THE SYSTEMS-ANALYSIS APPROACH IS PROPOSED AS A METHOD OF PREDICTING RESULTS OF DIFFERENT RECREATION-MANAGEMENT DECISIONS. SINCE THE KNOWLEDGE IS LACKING FOR MANY RECREATION-RESEARCH PROBLEMS, THIS PAPER EXPLORES THE POSSIBILITIES OF USING SYSTEMS ANALYSIS AND ATTEMPTS TO DEVISE A METHODOLOGY FOR CLASSIFYING CERTAIN ASPECTS OF THE APPROACH.
346. SHUBIK, M. 1955. THE USES OF GAME THEORY IN MANAGEMENT SCIENCE. MANAGE. SCI. 2(1):40-54. THE ESSENCE OF GAME THEORY IS DISCUSSED IN RELATION TO DECISION-MAKING IN MANAGEMENT. THE ELEMENTS OF GAME THEORY ARE INTRODUCED AND APPLIED TO BUSINESS PROBLEMS IN GENERAL AND PROBLEMS OF ADVERTISING, DISTRIBUTION, PRODUCTION, STATISTICS, CONTRACT BINDING, PRICE WARS, COMPETITION, COMMITTEE USE AND VOTING POWER, AND TEAMWORK.
347. SILVERSIDES, C. R. 1963. A SYMPOSIUM - LINEAR PROGRAMMING APPLIED TO WOOD PROCUREMENT. PULP AND PAP. MAG. CANADA 64(9):WR347, WR350-352, WR354-356, WR358, WR360, WR362-364. THE LINEAR PROGRAMMING MODEL CONCERNED OVERALL OPERATIONAL AND INVESTMENT DECISIONS IN EVALUATING COMPETING WAYS OF SUPPLYING A PARENT PULP MILL WITH WOOD. A SECOND APPROACH IS GAME THEORY, DERIVED FROM THE PROBABILITIES OF FACTORS AFFECTING MANAGEMENT AND LOGGING OPERATIONS.
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350. SJUNNESSON, S. 1969. SIMULATION, A TOOL FOR EVALUATING MECHANIZED THINNING SYSTEMS. INT. UNION FOR. RES. ORGAN. MTG. 8254-266. STOCKHOLM. A SIMULATION MODEL AIDS IN CHOOSING THE BEST THINNING SCHEDULE AND HARVESTING MACHINE SYSTEM IN ANY TYPE OF FOREST STAND. AND SIMULTANEOUSLY THE MODEL PROVIDES AN ESTIMATE OF THE OPERATION'S PROFITABILITY.
351. SKAAR, R. 1966. DIGITAL SIMULATION OF WAITING-LINE PROBLEMS AND ITS APPLICATION IN AN ANALYSIS OF A WOOD-HANDLING MODEL. M.S. THESIS, STATE UNIV. N.Y. COLL. FORESTRY, SYRACUSE. AN EXPLORATION OF SIMULATING A WAITING-LINE (QUEUING SITUATION) AND THE DESCRIPTION OF A SIMULATION MODEL FOR A HYPOTHETICAL WOOD PROCUREMENT PROBLEM.
352. SMITH, G. W. 1958. A METHOD OF DETERMINING THE OPTIMUM WAYS OF CONVERTING TREES INTO SAWLOGS. M.S. THESIS, NORTH CAROLINA STATE COLL., RALEIGH. LINEAR PROGRAMMING IS APPLIED TO THE LOG-MAKING PHASE OF THE LUMBER INDUSTRY. FIELD DATA WERE OBTAINED FOR CONSTRUCTING A STAND TABLE; THEN, VARIOUS METHODS WERE DEVISED FOR CUTTING TREES INTO LOGS, AND TIME AND COST VALUES AND NET PROFITS WERE CALCULATED PER TREE CLASS. THE LP SOLUTION THEN DETERMINED THE BEST LOG-MAKING PROCEDURE FOR MAXIMIZING THE PROFIT FUNCTION.
353. SMITH, G. W., AND C. HARRELL. 1961. LINEAR PROGRAMMING IN LOG PRODUCTION. FOREST PROD. J. 11(1):8-11. THE MODEL MAXIMIZES PROFIT, USING THE PRICES OF SAWTIMBER AND PULPWOOD, AND THE COSTS OF VARIOUS OPERATIONS, PARTICULARLY CROSCUTTING, INVOLVED IN THE CONVERSION FOR EACH DIAMETER CLASS. THE LIMITATIONS OF THE MARKET, POSTULATING CERTAIN RELATIONSHIPS BETWEEN THE QUANTITIES OF THE VARIOUS LOG LENGTHS OFFERED, ARE ALSO CONSIDERED.
354. SMITH, J. H. G., NEWNHAM, R. M., AND HEIJAS, J. 1965. IMPORTANCE OF DISTRIBUTION AND AMOUNT OF MORTALITY CAN BE DEFINED BY SIMULATION STUDIES. COMMONWEALTH FOREST REV. 44(3):188-192. THE

DISTRIBUTION OF MORTALITY IN PLANTATIONS AND NATURAL STANDS IS CONSIDERED. THE EFFECTS OF VARIOUS INTERMEDIATE AMOUNTS AND DISTRIBUTIONS OF JUVENILE MORTALITY CAN BE SIMULATED BY MANIPULATION OF STAND MODELS ON AN IBM 7040 COMPUTER. THE MODELS CAN ALSO BE USED TO TEST VARIOUS KINDS OF THINNING REGIMES.

355. SOROLEV, I. V., AND GONCARENKO, N. A. 1965. (ALGORITHM FOR PLANNING THE BREAKING DOWN OF SAWLOGS.) LESN. Z., ARHANGLISK 8(5):154-161. (IN RUSSIAN.) AN ALGORITHM IS DEVELOPED FOR PLANNING THE BREAKING DOWN OF SAWLOGS AS A STAGE IN THE UTILIZATION OF ELECTRONIC COMPUTERS FOR AUTOMATION OF SAWMILLING.
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358. SPFIDEL, G. 1970. (DECISION THEORY AS A BASIS OF RATIONALIZATION IN FORESTRY.) FORSTARCHIV, 41(2):25-30. A GENERAL ARTICLE WHICH INCLUDES A MODEL FOR MAXIMIZING SOCIAL-PRODUCT AND OTHER FOREST BENEFITS. THE IMPORTANCE OF INFORMATION AND DOCUMENTATION, AND OF TRAINING IN DECISION MAKING (GAME THEORY, ETC.) IS STRESSED.
359. STANG, H. 1964. (MODELS AS AIDS IN SOLVING PLANNING PROBLEMS: AN EXAMPLE SHOWING THE LAYOUT OF SKIDDING TRAILS.) FORSTARCHIV, 35(12):245-250. (IN GERMAN WITH GERMAN SUMMARY.) THE USES AND LIMITATIONS OF MATHEMATICAL MODELS IN FORESTRY ARE DISCUSSED AND A DETAILED ANALYSIS OF THE METHOD USING AN EXAMPLE OF SKID-TRAIL LAYOUT IS PRESENTED.
360. STEINLIN, H. 1970. MEANS OF REDUCTION OF DEPRECIATION OF PULPWOOD BETWEEN FELLING AND MANUFACTURING AT THE MILL. INT. UNION FOREST. RES. ORGAN. MTG.:192-200. ROYAL COLL. FORESTRY, STOCKHOLM. METHODS OF OPERATIONS RESEARCH CAN BE USED TO DETERMINE THE BEST MEANS OF LOGGING

TRANSPORTATION AND STORAGE OF PULPWOOD AND THE SCHEDULING OF THESE PROCESSES USING KNOWN VARIABLES.

361. STITELER, W. M., III. 1965. THE GENERATION OF FOREST MODELS BY SIMULATION ON A COMPUTER. M.S. THESIS, PA. STATE UNIV., UNIVERSITY PARK. COMPLETE DESCRIPTION OF THE SIMULATION MODEL, COMPUTER PROGRAM, AND OUTPUT IS PRESENTED FOR THE RESEARCH DESCRIBED IN THE FOLLOWING CITATION (STITELER, 1971).
362. STITELER, W. M., III, AND F. Y. BORDEN. 1967. THE GENERATION OF FOREST MODELS BY SIMULATION ON A COMPUTER. PA. STATE UNIV. SCHOOL FOREST RESOURCES, RES. BRIEFS 2(1):14-16. UNIVERSITY PARK. A BRIEF DESCRIPTION OF A PROJECT DESIGNED TO INVESTIGATE THE POSSIBILITY OF WRITING A FOREST MODEL-GENERATING PROGRAM FLEXIBLE ENOUGH TO GENERATE MODELS FOR A VARIETY OF SIMULATION PROBLEMS. THE PROGRAM (WRITTEN IN FORTRAN II) SUCCESSFULLY GENERATED MODELS FOR AN EVEN-AGED AND AN UNEVEN-AGED OAK STAND AND TWO SPECIFIC MIXED HARDWOOD STANDS.
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364. STOLTENBERG, C. H., AND G. H. THOMSON. 1962. OBSERVATIONS ON THE USEFULNESS OF LINEAR PROGRAMMING IN FARM FORESTRY. J. FOREST. 60(10):724-728. LINEAR PROGRAMMING IS A SPECIFIC TECHNIQUE FOR THE SELECTION OF THE BEST COMBINATION OF ACTIVITIES. HOWEVER, WITH RESPECT TO FARM FORESTRY, THERE ARE TWO SHORTCOMINGS: (1) MAXIMUM INCOME FROM AVAILABLE RESOURCES IS AN INADEQUATE EXPRESSION OF THE GOAL; AND (2) OPTIMUM SOLUTIONS MUST BE STABLE TO BE USEFUL IN PLANNING FARM FORESTRY ACTIVITIES, BUT SOLUTIONS DERIVED FROM LINEAR PROGRAMMING ARE LIKELY TO BE UNSTABLE.
365. STRAND, L. 1967. (PRICE TABLES FOR SCOTS PINE BY MEANS OF DYNAMIC PROGRAMMING.) MELDING, INSTITUTT. FOR SKOGTAKSASJON, NORGES LANDBRUKSHOG-SKOLE, VOLLEBEKK, 818-10, 63. (IN NORWEGIAN WITH ENGLISH SUMMARY.) DYNAMIC PROGRAMMING IS USED TO SELECT THE LOG LENGTHS (FROM CROSSCUTTING) THAT WILL GIVE THE BEST PRICE.

A TABLE SHOWING THE GROSS VALUE PER TREE AND THE NUMBER OF LOGS FOR TREES OF DIFFERENT SIZES IS INCLUDED.

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368. SYDNEYSMITH, S. 1964. AN APPLICATION OF LINEAR PROGRAMMING TO LOG ALLOCATION IN THE FOREST INDUSTRY OF BRITISH COLUMBIA. M.S. THESIS, UNIV. BRITISH COLUMBIA, VANCOUVER. A LINEAR PROGRAMMING LOG-ALLOCATION MODEL IS PRESENTED, BASED ON AN INTEGRATED INDUSTRY IN THE COASTAL REGION OF BRITISH COLUMBIA. THE MODEL ENCOMPASSES THREE MAIN CATEGORIES OF LOG-USE; SAWMILLING, PLYWOOD PRODUCTION, AND PULPWOOD PRODUCTION, AND DEMONSTRATES HOW A GIVEN SUPPLY OF LOGS MAY BE OPTIMALLY DISTRIBUTED AMONG THESE STRUCTURALLY DIFFERENT LOG-CONVERSION PROCESSES.
369. SZABO, K. 1970. LINEAR PROGRAMMING OF SAWMILL PRODUCTION. TRANSL. DEP. FISH. FOR. CAN. 00FF-87, 41 PP. (TRANSL. FROM FAIP, KUTATAS, PP. 217-245, 1967.) THE PAPER APPLIES LINEAR PROGRAMMING TO PRODUCTION CONTROL IN THE SAWMILL INDUSTRY. ALL POSSIBLE CUTTING COMBINATIONS ARE ARRANGED IN A TABLE SHOWING THE RESULTING YIELDS FROM ONE CUBIC METER OF WOOD FOR EACH CUTTING ALTERNATIVE. BASED ON THE TABLE, CONSTRAINTS ARE SPECIFIED ON THE QUANTITIES OF LUMBER PRODUCED BY ALTERNATIVE CUTTING METHODS. THE OBJECTIVE FUNCTION IS TO MINIMIZE THE TOTAL AMOUNT OF RAW MATERIAL (LOGS) TO ACHIEVE A GIVEN PRODUCTION MIX.

370. TABOR, H. B. 1968. DETERMINING CHIP-PIPELINE POTENTIALS WITH LINEAR PROGRAMMING. FOREST PROD. J. 18(6):29-32. A PROGRAMMING MODEL IS DEVELOPED, BASED ON CONDITIONS IN SOUTHWEST ALABAMA FOR DETERMINING OPTIMUM FLOW PATTERNS FOR TRANSPORT OF WOOD CHIPS BY WATER SLURRY.
371. TCHENG, T. H. 1966. SCHEDULING OF A LARGE FORESTRY-CUTTING PROBLEM BY LINEAR PROGRAMMING DECOMPOSITION. PH.D. DISS., UNIV. IOWA, IOWA CITY. A LINEAR PROGRAMMING DECOMPOSITION MODEL IS DEVELOPED FOR THE OPTIMAL SCHEDULING OF AN ACTUAL HARVESTING PROBLEM INVOLVING 1,166 WOODLANDS OVER A 24-YEAR PERIOD. THE COMPUTATIONAL ALGORITHM AND COMPUTER PROGRAM FOR THE DECOMPOSITION METHOD ARE ALSO DEVELOPED. BOTH INTEGER AND NONINTEGER SOLUTIONS ARE CONSIDERED IN THE COMPLEX PROBLEM, WHICH HAD TO BE TERMINATED AFTER THE 960TH ITERATION BECAUSE OF COMPUTER ROUND-OFF ERROR. HOWEVER, RESULTS SHOW THAT TERMINATION CAN BE APPLIED SOONER WITHOUT SIGNIFICANT LOSS IN TOTAL WOOD PRODUCTION.
372. TCHENG, T. H. 1966. SCHEDULING OF A LARGE FORESTRY-CUTTING PROBLEM ON A DIGITAL COMPUTER BY DECOMPOSITION OF LINEAR PROGRAMMING. INST. MANAGE. SCI. (TIMS) MTG. PAP. DALLAS, TEX. DECOMPOSITION OF A LINEAR PROGRAMMING MODEL FOR THE SCHEDULING OF A VERY LARGE FOREST-CUTTING PROBLEM IS PRESENTED. A COMPUTATIONAL ALGORITHM AND A COMPUTER PROGRAM PACKAGE DESIGNED FOR THIS MODEL ARE DISCUSSED.
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374. TERTICKIJ, M. I. 1964. (THE PREREQUISITES OF ALGORITHMS FOR (PROGRAMMING) CALCULATION AND PLANNING WORK IN LOGGING.) LESN Z., ARHANGEL'SK 7(4):158-164. (IN RUSSIAN.) NO ENGLISH SUMMARY AVAILABLE.

375. TEXAS FOREST PRODUCTS LABORATORY. 1970. OPERATIONS RESEARCH IN THE FOREST PRODUCTS INDUSTRY. TEX. IND. WOOD SEMINAR 4, 62 PP. LUFKIN, TEX. CONTENTS: SURVEY OF OPERATIONS RESEARCH, COST MODELING, OPTIMIZATION, COMPUTER USES IN OPERATIONS RESEARCH AND OPERATIONS-RESEARCH APPLICATIONS IN THE FOREST PRODUCTS INDUSTRY.
376. THEIL, H., J. C. G. BOOT, AND T. KLOEK. 1965. OPERATIONS RESEARCH AND QUANTITATIVE ECONOMICS, 258 PP, NEW YORK: MCGRAW-HILL BOOK CO. CHAPTERS ON: LINEAR PROGRAMMING, THE OPTIMUM PATH AND THE CRITICAL PATH, INPUT ANALYSIS, ECONOMETRIC MACROMODELS, ECONOMIC FORECASTS, UNCERTAINTY AND PROBABILITY, THE CONCEPT OF A STRATEGY, GAME THEORY, QUEUES, SIMULATION AND MANAGEMENT GAMES, PRODUCTION AND INVENTORY DECISIONS, THE STATISTICAL SPECIFICATION OF ECONOMIC RELATIONS, AND THE CONSUMER'S DOLLAR.
377. THEILER, T. 1959. LINEAR PROGRAMMING AND OPTIMAL CUTTING PRACTICES. AMER. PAPER IND. 41(6):384-388. A COMMON PROBLEM OF WOODLAND MANAGERS IS TO DETERMINE AN OPTIMUM CUTTING POLICY TO SUPPLY THE NEEDS OF THEIR PULP AND PAPER MILLS. THIS ARTICLE SHOWS HOW THE MANY CONSIDERATIONS INVOLVED IN AN OPTIMUM CUTTING POLICY CAN BE EXPRESSED IN MATHEMATICAL TERMS, REDUCED TO A MATRIX FORM, AND SOLVED BY LINEAR PROGRAMMING TECHNIQUES. THE AUTHOR WORKS WITH HYPOTHETICAL DATA CONCERNING A PAPER MILL AND FOUR WOODLAND AREAS THAT CAN SUPPLY THE MILL WITH PULP.
378. THOMPSON, E. F. 1963. COMMENTS ON OBSERVATIONS ON THE USEFULNESS OF LINEAR PROGRAMMING IN FARM FORESTRY. J. FOREST. 61(1):57-58. THE OBJECTIVES AND AVAILABLE RESOURCES ALONG WITH THE QUANTITATIVE RESTRICTIONS PLACED ON THESE RESOURCES BOTH PHYSICALLY AND BY THE FARMER'S OBJECTIVES ARE THE CORE OF ANY LINEAR PROGRAMMING PROBLEM. THESE FACTORS DETERMINE THE DECISION. ALL LINEAR PROGRAMMING DOES IS GUARANTEE THAT THIS DECISION IS THE OPTIMUM -- GIVEN THE OBJECTIVES, RESOURCES, AND RESTRICTIONS.
379. THOMPSON, E. F. 1967. CONSIDERATION OF UNCERTAINTY IN FOREST MANAGEMENT DECISION MAKING. DISS. ABSTR. 27(8):2562B-2563B. BAYESIAN DECISION THEORY ALLOWS UNCERTAINTY TO BE SYSTEMATICALLY RECOGNIZED IN THE PROCESS OF MAKING DECISIONS. DECISIONS MADE TODAY ARE DEPENDENT UPON THE UNCERTAIN FUTURE LEVELS OF VARIOUS FACTORS.

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381. THOMPSON, E. F., AND D. P. RICHARDS. 1969. USING LINEAR PROGRAMMING TO DEVELOP LONG-TERM, LEAST-COST WOOD PROCUREMENT SCHEDULES. PULP AND PAPER MAG. CAN. 70(C):172-175. WOOD PROCUREMENT IS CHARACTERIZED AS AN ALLOCATION PROCESS SOLUBLE BY LINEAR PROGRAMMING. AN EXPLANATION IS GIVEN OF A MODIFICATION OF THE GENERAL LINEAR PROGRAMMING MODEL, LINEAR PROGRAMMING OVER TIME, WHICH IS THE APPROPRIATE TECHNIQUE WHEN THE ALTERNATIVES ARE TO BE ALLOCATED AMONG PERIODS WITHIN A FIXED TIME SPAN.
382. THOMPSON, E. F., ET. AL. 1968. LINEAR PROGRAMMING OVER TIME TO ESTABLISH LEAST-COST WOOD PROCUREMENT SCHEDULES. VA. POLYTECH. INST. RES. DIV. BULL. 29, 70 PP. BLACKSBURG. LINEAR PROGRAMMING OVER TIME IS EXPLAINED AND IS PRESENTED AS AN EFFICIENT TECHNIQUE FOR SOLVING THE GENERAL WOOD-PROCUREMENT PROBLEM OF AN INTEGRATED FOREST PRODUCTS COMPANY. ITS USE IS ILLUSTRATED BY A CASE STUDY IN WHICH AN ACTUAL FIRM'S PROCUREMENT PROBLEM IS FORMULATED AND SOLVED; THE SOLUTION PROVIDING A SCHEDULE OF ACTIVITIES THAT WOULD MINIMIZE THE PRESENT VALUE OF WOOD-PROCUREMENT LOSSES FOR THE NEXT 20 YEARS.
383. TILGHMAN, W. B. 1967. LINEAR PROGRAMMING APPROACH TO MINIMIZING WOOD PROCUREMENT COST FOR INTEGRATED FOREST PRODUCT FIRMS. M. S. THESIS, VA. POLYTECH. INST., BLACKSBURG. A LINEAR PROGRAMMING COST MINIMIZATION PROBLEM IS PRESENTED, USING AN INTEGRATED FOREST PRODUCTS FIRM WHOSE OBJECTIVE IS TO MINIMIZE THE PRESENT VALUE OF WOOD PROCUREMENT COSTS OVER A 20-YEAR PERIOD. THE FIRM'S PRESENT AND THREE ALTERNATIVE PRICE STRUCTURES ARE USED. PRODUCT QUALITY AND MANAGERIAL CONSTRAINTS ARE USED AND TIMBER GROWTH IS INCORPORATED INTO THE SELECTION OF PROCUREMENT ALTERNATIVES.
384. TORIN, L. R., AND J. S. BETHEL. 1969. VENEER RECOVERY PREDICTION AND ANALYSIS THROUGH COMPUTER SIMULATION. WOOD + FIBER 1(2):97-107. THE PROJECT WAS DESIGNED TO ASSEMBLE A DATA BANK OF INFORMATION ON VENEER QUALITY AND A SIMULATION MODEL TO BE USED IN EVALUATING VENEER GRADE

RECOVERY IN RELATION TO QUALITY SPECIFICATIONS AND MANUFACTURING CRITERIA. GREEN-VENEER CHARACTERISTICS FROM PHOTOGRAPHS TAKEN BEHIND THE LATHE ARE CONVERTED TO DIGITAL INPUT DATA BY MEANS OF AN X-Y COORDINATE SYSTEM. THE SIMULATOR ALLOWS FOR MANIPULATION OF GRADE REQUIREMENTS, SHEET WIDTHS, AND CLIPPING SPECIFICATIONS.

385. TSOLAKIDES, J. A. 1968. A SIMULATION MODEL FOR LOG YIELD STUDY. DISS. ABSTR. 29B(6):1904. A MODEL IS PROGRAMMED IN FORTRAN, FOR DETERMINING THE EFFECT OF ALTERNATIVE SAWING METHODS ON THE GRADE AND VOLUME YIELD OF A LOG.
386. TSOLAKIDES, J. A. 1969. A SIMULATION MODEL FOR LOG YIELD STUDY. FOREST PROJ. J. 19(7):21-26. SIX OAK LOGS, SAWN INTO 1-INCH DISCS, PROVIDED INPUT DATA ON THE EXTERNAL AND INTERNAL QUALITY CHARACTERISTICS, INCLUDING SIZE AND LOCATION OF DEFECTS. INPUT ALSO INCLUDED VARIANTS ON THREE METHODS OF SAWING TO GIVE 164 POSSIBILITIES. THE COMPUTER TECHNIQUE DEVELOPED INDICATED THE LUMBER GRADE YIELDS AND VALUE FOR EACH SAWING VARIANT, AND IS INTENDED TO PROVIDE A METHOD FOR DECIDING HOW BEST TO CONVERT GRADED LOGS.
387. TURNER, G. J. 1966. LINEAR PROGRAMMING IN CHIP FIBER AND PULP MARKETING. SEMINAR ON OPER. RES. IN FOREST PROD. IND. PROC.:7-21. IBM CORP., LOS ANGELES, CALIF. PRACTICAL USE OF AVAILABLE TOOLS FOR LINEAR PROGRAMMING IN MARKETING OF PULP: PROBLEM DEFINITION, DATA PROCUREMENT, AND THE VERIFICATION AND USE OF RESULTS.
388. TURNER, G. J. 1969. PLANNING FOR MATERIAL FLOW ORGANIZATIONS IN WOOD PRODUCTS INDUSTRIES. DISS. ABSTR. 29A(9):2844-2845. A LINEAR PROGRAMMING MODEL IS DEVELOPED FOR MID-TERM PLANNING IN A WOOD-PRODUCTS FIRM. ASSUMING PRODUCT PRICES, SALES VOLUME, YIELD VECTORS, AND CONVERSION COSTS; THE SELECTION OF AREAS TO BE LOGGED, THE ALLOCATION OF LOGS TO PROCESSES, THE DETERMINATION OF EFFICIENT CONVERSION CAPACITIES, AND PRODUCT-MIX, CAN BE ANALYZED SIMULTANEOUSLY. FOR SHORT-TERM OPERATIONS, MECHANISMS ARE PROPOSED FOR RESPONDING TO ORDERS, ALLOCATING ORDERS TO MILLS, ETC.
389. UNITED AIRCRAFT OF CANADA, LTD. 1966. A STUDY INTO THE USE OF AIRCRAFT IN THE CONTROL OF FOREST FIRES. THE OPERATIONS MODEL. PART I - ANALYSIS, PART II - RESULTS. UNITED AIRCRAFT OF CAN. REP. H-1035, 58 PP. LONGUEUIL, QUE., CAN. A DETAILED

COMPARATIVE ACCOUNT OF SIX MODELS DESIGNED TO SIMULATE FOREST FIRE SUPPRESSION OPERATIONS (FIVE BASED ON USE OF FIXED-WING AIRCRAFT AND HELICOPTERS IN BOTH TRANSPORT AND WATER-BOMBING ROLES, AND ONE ON OPERATIONS WITHOUT AIRCRAFT), AND TO PERMIT A DETAILED ESTIMATE AND ANALYSIS OF COSTS.

390. VAJDA, S. 1961. MATHEMATICAL PROGRAMMING. 310 PP., ILLUS. READING, MASS.: ADDISON-WESLEY PUBLISHING CO. CONTENTS: THE ALGEBRA OF LINEAR INEQUALITIES, THE ALGEBRA OF DUALITY, THEORY OF GRAPHS AND COMBINATORIAL THEORY, GENERAL ALGORITHMS, SPECIAL ALGORITHMS, USES OF DUALITY, SELECTED APPLICATIONS, PARAMETRIC LINEAR PROGRAMMING, DISCRETE LINEAR PROGRAMMING, STOCHASTIC LINEAR PROGRAMMING, NONLINEAR PROGRAMMING, AND DYNAMIC PROGRAMMING.
391. VALG, L. 1966. SIMULATION OF FOREST STAND GROWTH. UNIV. OREG. FOREST INDUS. MARKET, CONF. PROC. 3:43-50. BY USING MATHEMATICAL MODELS TO SIMULATE FOREST STAND GROWTH, FOREST MANAGERS CAN ESTIMATE QUANTITY AND QUALITY OF TREES TO BE HARVESTED, TIMING OF HARVEST, AND KIND AND AMOUNT OF INVESTMENT NEEDED TO ACHIEVE DESIRED FOREST-MANAGEMENT OBJECTIVES.
392. VAN DYNE, G. M. 1966. APPLICATION AND INTEGRATION OF MULTIPLE LINEAR REGRESSION AND LINEAR PROGRAMMING IN RENEWABLE RESOURCE ANALYSES. J. RANGE MANGE. 19(6):356-362. PRELIMINARY RESULTS OF SPECIFYING THE RELATIONSHIPS BETWEEN CERTAIN FACTORS AND VARIOUS NUTRIENT PRODUCTION MEASURES ARE PRESENTED. THESE RELATIONSHIPS ARE USED IN LINEAR PROGRAMMING MODELS TO DETERMINE THE OPTIMUM PROTEIN PRODUCTION ON A FOOTHILL RANGE. SITE CHARACTERISTICS FOR OPTIMUM PROTEIN PRODUCTION WERE CONSTRAINED TO FALL WITHIN THE RANGE OF VARIABLES MEASURED AND WERE CONSTRAINED TO SATISFY CERTAIN INHERENT RELATIONSHIPS KNOWN ABOUT THESE VARIABLES.
393. VASILEV, S. 1965. (LINEAR PROGRAMMING AND ITS APPLICATION IN FOREST PLANNING.) GORSKO STOPANSTVO 21(11):14-21. (IN BULGARIAN.) NO ENGLISH SUMMARY AVAILABLE.
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THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

SHRUBS AND VINES FOR NORTHEASTERN WILDLIFE

Edited by the
NORTHEASTERN FOREST EXPERIMENT STATION
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W.M.H.

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When the Northeastern Deer Study Group, sponsored by the Association of Northeast Game, Fish, and Conservation Commissioners, agreed to take on the job of producing this handbook, Chairman James S. Lindzey of the Pennsylvania Cooperative Wildlife Research Unit appointed Stephen A. Liscinsky of the Pennsylvania Game Commission and John D. Gill of the U.S. Forest Service to lead the project. They in turn called on Robert D. McDowell of the University of Connecticut, Earl F. Patric of the New York State University College of Forestry, and Ward M. Sharp of the USDI Bureau of Sport Fisheries and Wildlife for advice and review of plans.

Deer Study Group members in nearly all the northeastern states and provinces participated in selecting the species included in the report and in recruiting authors. At least 21 people functioned as key-men for individual areas or agencies. We cannot name all of them, but Joseph S. Larson of the University of Massachusetts and Stuart L. Free of the New York Department of Environmental Conservation were especially active in recruiting authors. When word of the handbook spread beyond the Northeast, we got additional help from Forest W. Stearns, then with the North Central Forest Experiment Station at Rhinelander, Wisconsin. Stearns' interest confirms that this handbook should be useful in the Great Lakes area as well as in the Northeast.

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So many other people helped that we do not have space to name all of them. But we must particularly thank Earl L. Core, who helped and encouraged us throughout this project.

—JOHN D. GILL and WILLIAM M. HEALY

SHRUBS AND VINES FOR NORTHEASTERN WILDLIFE

Compiled and revised by

JOHN D. GILL and WILLIAM M. HEALY

JOHN D. GILL leads the Northeastern Forest Experiment Station's wildlife-habitat research project at the Forestry Sciences Laboratory, 180 Canfield Street, Morgantown, West Virginia 26505, in cooperation with West Virginia University. Gill is a member of the University's graduate faculty in the Division of Forestry. He joined the Forest Service in 1967 after service in the Maine Department of Inland Fisheries and Game (Orono, 1955 to 1967) and the West Virginia Conservation Commission (Elkins, 1950 to 1955). While attending Michigan State University (1947 to 1950) he worked part-time for the Michigan Game Division.

WILLIAM M. HEALY, associate research wildlife biologist, has worked with Gill since completing master's degree studies at the Pennsylvania State University in 1967. His research mostly concerns habitat requirements of wild turkeys. He also holds the rank of instructor in the West Virginia University Division of Forestry and is working toward a Ph.D. degree in animal behavior.

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A HANDBOOK ON SHRUBS AND VINES

By John D. Gill and William M. Healy

*USDA Forest Service
Northeastern Forest Experiment Station
Forestry Sciences Laboratory
Morgantown, West Virginia*

This handbook was prepared to provide practical information about managing the shrubs and woody vines of the Northeast that are important to wild birds and mammals for food and protective cover.

This work stemmed from forest-wildlife research needs expressed in a series of analyses begun within the Northeast Section of The Wildlife Society and later sponsored by the Association of Northeast Game, Fish, and Conservation Commissioners. A committee organized by federal-aid supervisors in the USDI Bureau of Sport Fisheries and Wildlife at Boston recommended preparation of a handbook to pull together available information that would be useful in the management of shrubs and vines for wildlife. The committee noted that, though several recently published handbooks provided information about commercially valuable tree species, no such handbook was available for the smaller woody plants.

Work on the handbook began in 1967 when the Northeastern Deer Study Group, sponsored by the Commissioners, agreed to take on the job.

As the first step in planning the handbook, we listed nearly all the shrubs and woody vines that had been reported to have some kind of value for wildlife. Then biologists

throughout the Northeast were asked to review the list and rate the plants to help us select the most important species to include.

The selected list includes plants in 36 genera and 100 species. Besides the native plants, we included three exotics that have become widely naturalized: a rose and two honeysuckles.

There may be some bias in the selection, because most of the wildlife biologists who participated in selecting the plants had been working almost exclusively with game species, and many were specialists on deer. However, we feel that this bias is not serious, because many groups of game animals and non-game animals have similar habitat requirements.

We made no attempt to illustrate the plants for purposes of identification. Illustrated field guides to woody plants are readily available, as are state and provincial flora publications.

The handbook contains 41 chapters by different authors. To avoid repetition, literature references have been consolidated into a single list at the back of the book. A glossary of terms is also appended.

The authors hope that this handbook will prove useful not only to wildlife managers, but also to anyone who owns or manages land or is interested in providing favorable habitat for wildlife.

ECOLOGY OF SHRUBS AND VINES

By Ward M. Sharp

Bureau of Sport Fisheries and Wildlife
Warren, Pennsylvania

The ecology of shrubs and woody vines concerns the interactions among shrubs and vines, other plants, animals, and the environment. As examples, interactions of shrubs with other plants and with fire have an impact on the welfare and development of shrubs in the landscape. Animals play a key role, exerting both beneficial and detrimental effects.

Shrubs cannot be defined exactly. Generally, they are low, erect, woody plants, usually under 25 feet in height, and usually have several stems. Any definition is arbitrary because of the great variation in height and form. The person who is not familiar with either trees or erect shrubs may encounter difficulty in distinguishing tree regeneration or small trees from shrubs.

GROWTH FORMS

Individual species fall into one, or in some cases more than one, of the following categories: (1) erect shrubs, either clonal, multi-stemmed, or single-stemmed; and (2) climbing or trailing shrubs or vines.

Clonal shrubs and vines form dense colonies from underground, horizontal rootstocks. Colonies may develop from a single seedling. Smooth sumac (*Rhus glabra*) grown from seed will start clonal development by the fifth year. Other plants of clonal habit, for example, are lowbush blueberries (*Vaccinium* spp.), gray-stemmed dogwood (*Cornus racemosa*),

blackberries (*Rubus* spp.), and the low serviceberries (*Amelanchier* spp.). In optimal sites American elder (*Sambucus canadensis*) may become clonal. Fire stimulates seed germination in all clonal species, and some species such as lowbush blueberries need to be burned on a rotation basis.

The multi-stemmed shrubs include those that produce numerous stems from a common root collar. Typical examples are the highbush blueberries, witherod (*Viburnum cassinoides*), and mountain laurel (*Kalmia latifolia*).

Single-stemmed shrubs include many of the tall species. Shrubs in this group grow from a single stem, or sometimes two or more stems may originate from near ground level. Flowering dogwood (*Cornus florida*), hawthorns (*Crataegus* spp.), and hophornbeam (*Ostrya virginiana*) belong in this category.

Climbing or trailing woody shrubs or vines are ecologically similar to erect shrubs, although in appearance the relationship may seem remote. The vine growth form may hold for all species of a genus such as grape (*Vitis*) or greenbrier (*Smilax*), but not for all species of genera such as honeysuckle (*Lonicera*) or bramble (*Rubus*).

The climbing vines often use erect shrubs or trees for support and access to sunlight. Woody vines, like wild grape, usually become established at the same time as new tree and shrub regeneration. Once established, they

grow along with their supporting plants. They seldom take hold in forest stands once the trees attain pole-timber size. Trailing vines such as dewberries (*Rubus* spp.) usually grow in open fields. They compete for sunlight with grasses and forbs by trailing over the herbaceous plants.

ENVIRONMENTAL FACTORS

The principal factors that interact on shrubs are (1) physical—sunlight, soils and moisture, temperature, and fire; and (2) biological—browsing, insects and disease, and seed dispersal by animals.

Sunlight

Among all the environmental factors, full sunlight is most important for nearly all species. When luxuriant shrubs are shaded by the dense canopy of invading trees, most species become suppressed and wane regardless of other factors such as moisture, temperature, and soil nutrients. When taller shrubs are shaded after they reach normal height, they may persist longer than the low-growing species. Those that persist are suppressed. Their vigor wanes and their fruiting potential declines.

There are exceptions to this, however. A few species grow well in partial or full shade. But the majority grow best and produce the most fruit in openings such as road edges, old fields, and clearcut forest stands.

From the importance of full sunlight in the life span of most shrub communities, one may reason that shrubs evolved in a grassland or a forb-grass environment. They transformed these sites into savannas that later were invaded by trees. Man and fire have played leading roles in perpetuating sunlight exposure in the shrub community.

Soils and Moisture

Soil and moisture are combined here because shrubs tolerate a wide range of soil and moisture conditions. Some shrubs occur in wet sites while others need dry upland sites. This requirement varies even among species of the same genus, such as blueberries. Lowbush blueberries require dry upland soils; native

highbush blueberries establish best in wet soils or soils that are waterlogged in spring.

Some shrubs prefer soils of limestone origin; others prefer acid soils of sandstone origin; and others are tolerant of a wide range of soil and moisture conditions. This trait also varies among species within a genus such as serviceberry, dogwood, and hawthorn. The shrubby roundleaf serviceberry (*A. sanguinea*) occurs in Pennsylvania on limestone soils, while downy serviceberry (*A. arborea*) is common throughout the state.

It is pointless to try to lay down hard and fast rules on the soil and moisture requirements of shrubs and vines in general. These needs are as variable as the needs among tree species.

Temperature

Temperature is most important during flowering and setting of the fruit crop. When temperatures drop below freezing during flowering, the entire fruit crop may be eliminated. In other respects, native shrubs in the region are adapted to temperature extremes in winter.

Fire

Fire has been a key factor in the shrub community for so long that many species evolved through periodic occurrence of fire. Consequently, many shrubs are fire-adapted. The known fire-adapted species are those that form clonal colonies from a horizontal root system. Many of the multi-stem groups benefit from the influence of periodic burning. Shrubs of the heath family such as blueberries, huckleberries, and mountain laurel are rejuvenated by periodic burning.

Fire serves four roles in shrub management. It is a pruning and sanitation agent for cleaning up dead or decadent stems; it tends to set back tree regeneration; it is conducive to breaking seed dormancy and stimulating germination; and it helps control disease and insects.

For fire to serve best, it must be used periodically and in a prescribed manner. Except for lowbush blueberries, the optimum intervals between burnings have not been resolved. Pre-

scriptions should give season, moisture conditions, and the method under which fire is used. Optimal benefits are usually derived from burning in early spring. Burning in droughty periods or after leaves have unfolded may be more detrimental than beneficial. The beneficial role of fire in shrub management is neither widely recognized nor practiced in wildlife management.

Browsing

The impact of browsing on shrub or vine species depends largely on their palatability to browsing animals, mainly deer, rabbits, rodents, and livestock. Most shrubs are vulnerable only at a particular stage in their life cycle, such as the seedling and early regeneration stages.

The tops of some clonal and multi-stem shrubs never grow beyond the reach of browsing mammals. Therefore these shrubs have developed growth qualities that resist browsing. Crowns of low hawthorns, for example, become hedged from browsing; and the thorny, hedged crowns prevent overbrowsing. Inhibiting substances which render some shrubs unpalatable are known. Mountain laurel is toxic to some hooved animals, especially sheep; and elderberries are unpalatable to cattle.

The effects of browsing by deer may vary because of changes in factors other than the browsing itself. For example, Pennsylvania had a large deer herd in 1930 to 1960. In that period, a closed-canopy poletimber forest also developed. Such shrubs as mountain laurel and the scrub oaks—lightly browsed by deer and intolerant to shading—died beneath the closed canopy of trees. Therefore all factors of the shrub environment must be evaluated before damage is attributed exclusively to deer.

Cottontails and woodchucks prefer seeding shrubs under 24 inches in height. In my attempts to propagate American elder in wildlife areas, woodchucks and cottontails were as destructive as deer. Mice girdle shrubs at ground level; consequently, their damage may go undetected.

Insects and Diseases

The detrimental impact of insects and fungous diseases may be greater than that of browsing mammals. This impact may be local, it may go undetected, or it may be more prevalent among certain groups of shrubs than among others.

Insects are principally defoliators, but some attack the succulent shoot tips or the woody branches. Defoliators are periodic as a rule, but complete defoliation even for one season can trigger a decline in shrub vigor. I have observed that defoliation in a colony of gray dogwood was followed by failure to set fruit in the following years and by top dieback. Sucking insects such as lace bugs and aphids may destroy the leaf chlorophyll, leaving the foliage with a seared to brownish appearance by August. Aphid attacks on succulent shoot tips in seedling shrubs can weaken plants so that they succumb to winter-kill or drought.

The fungous diseases most frequently encountered among shrubs are those that attack the flowers, fruits, leaves, and stems. Those attacking the rootstocks are little known except by pathologists and may go undetected. Rust, leaf spot, and mildew are the diseases most frequently observed.

Many of the fungi may affect the flowers and fruits, thus reducing fruit quality and yield. Affected fruits either drop prematurely or those that persist are deformed or mummified (Heald 1926). Fruits of wild grapes are commonly mummified by fungous diseases. Rust diseases may be fatal. For example, hawthorn rust is often fatal where the alternate host, eastern redcedar (*Juniperus virginiana*), is common. Leaf spot diseases kill parts of the leaves, thus reducing photosynthetic activity. They also affect the flowers and fruits. The impact of disease on shrubs results in unthrifty or undernourished plants or total kill.

Prescribed or controlled burning in shrub communities will help control fungous diseases, such as leaf spot, and some defoliating insects. But rust control is realized only by removal of the alternate host. Fungicidal sprays are not considered economically feasible for native shrubs. Spraying insecticides for leaf defoliators is also impractical in managing shrubs in a unit of wildlife range.

Seed Dispersal by Animals

Shrubs and vines that produce berries or fleshy fruits depend on birds and mammals for seed dispersal. Seeds of these fruits are mostly small with hard seedcoats; and when eaten by most birds and some mammals, they are passed through the digestive tract either unharmed or treated so as to increase germinative capacity (Krefting and Roe 1949).

Birds are more efficient disseminators than mammals. In bird droppings, seeds are more widely dispersed, and fewer seeds are deposited at one site. Mammals such as raccoons and foxes deposit numerous seeds at a spot.

But birds and mammals may destroy those seeds that have a large endosperm, such as hazelnuts (*Corylus spp.*), scrub oak acorns (*Quercus ilicifolia*), or chokecherry (*Prunus virginiana*). Small rodents, in particular, consume the embryo along with the endosperm.

LAND USE

The era of native shrubs and vines probably reached its peak between 1900 and 1920 in the Middle Atlantic and Northeastern States. Up to that time, vast acreages had been converted to farm and pastureland. Livestock production equalled that of row crops. Lumbering operations had converted extensive areas to brushland. Use of fire in the landscape was a common and accepted practice. The period before 1920 was the agricultural era in the region.

Farm and pasture abandonment was characteristic of the decades after 1920. Beginning about 1933, fence rows between fields were being eliminated in a move toward clean farm-

ing. Land in farms and pastures in New York, for example, totalled 22,600,795 acres in 1910, but by 1950 farm abandonment had reduced this area by 40 percent to 13,672,937 acres (Conklin 1954). A similar or even greater abandonment of farm and pasture land since 1910 or earlier has occurred in most northeastern states. (Frey et al. 1957). The trend is continuing.

It has not been generally realized that in the agricultural era, conditions of rural living (including clearing and burning, extensive acres of pastureland, fence rows, and early lumbering operations) enabled native shrubs to flourish and increase in abundance. Now, with clean farming, use of herbicides, and conversion of abandoned farms to a closed-canopy forest, native shrubs have declined in sites where they were formerly abundant. These conditions point up the need for an aroused interest in the ecology and management of native shrubs and vines.

Beginning in the 1930s, shrubs from other parts of the world took precedence over native species. Much emphasis has been placed on exotic species for wildlife and soil-erosion plantings since that time. Consequently, native species received little study except by a few individuals who recognized the limitations and risks of exotics compared to native species. Even with the emphasis on planting millions of exotics in wildlife habitats, they have contributed little forage or fruits for wildlife. Having conducted studies in shrub ecology over the past two decades in Pennsylvania, I can only view the future with concern if interest in native shrubs continues to lag as in the past four decades.

ALDERS

SPECKLED ALDER, *Alnus rugosa* (Du Roi) Spreng. Also called Hoary or Tag Alder.

HAZEL ALDER, *Alnus Serrulata* (Ait.) Willd. Also called Common, Smooth, and Streambank Alder.

By William M. Healy and John D. Gill

*Northeastern Forest Experiment Station
Morgantown, West Virginia*

RANGE

The combined ranges of the two species include the entire region. Speckled alder occurs from Newfoundland to British Columbia and southward to Maryland, West Virginia, Ohio, northern Indiana, and Minnesota. Hazel alder grows as far north as Maine and ranges southward to Florida and Texas (Gleason 1963b).

HABITAT

Speckled alder is the more northern species. It is most common along the northern boundary of the United States (Brickman 1950) and is restricted to higher elevations at the southern edge of its range. In West Virginia, hazel alder grows mostly at elevations below 2,600 feet, while speckled alder is common in the mountains above 2,600 feet (Strausbaugh and Core 1952-64). Optimum growing conditions for the alders have not been described, but it is possible that climatic factors limit both species at the edges of their ranges.

Alders most commonly occupy poorly drained soils. Typically, they border streambanks and form thickets where surface drainage is slow and the ground-water level is near

the surface during part of the growing season. Saturated soil appears to be required for seed germination.

One study showed that saturation for intervals of 1 to 16 days stimulated growth of newly emerged hazel alder seedlings (McDermott 1954). In a study in northern Michigan, Brickman (1950) found speckled alder growing only on sites that had a saturated soil during the spring months, although some alder sites became dry during late summer. From this and other observations, he felt that speckled alder requires a saturated soil on which to germinate and become established.

Speckled alder grows well on a variety of soils, including rocky till, sandy loam, gray forest soils, and muck. The range of tolerance to alkalinity or acidity could not be found, but is probably similar to that of European alder (*A. glutinosa* [L.] Gaertn.) and European speckled alder (*A. incana* [L.] Moench.), which grew well on Ohio spoil banks with a pH range of 3.4 to 7.7 (Lowry et al 1967).

In the oak-hickory region, flood plains commonly support stands of alders and willows; if undisturbed, these shrubs give way to American sycamore, elms, red maple, and sweetgum.

In northern forests, alders grow with willows and heath shrubs as well as tamarack, birches, aspens, and conifers (Shelford 1963).

About 80 species of plants were found growing in hazel alder stands in Pennsylvania, but silky dogwood, black willow, jewelweed (*Impatiens* spp.), and sensitive fern (*Onoclea sensibilis*) were the most characteristic (Liscinsky 1972:35). Blackberries, common chokeberry, American elm, goldenrod (*Solidago* spp.), bluegrass (*Poa* spp.), and asters (*Aster* spp.) were also common associates (Liscinsky 1972:35).

LIFE HISTORY

Individual alders bear male and female flowers on separate catkins. Flowering occurs in April-May on catkins formed during the preceding year (Basset et al 1961). Wind spreads the pollen. The seed matures in egg-shaped conelets. Seed occasionally ripens as early as August and is usually fully ripe by September or October (U. S. Forest Service 1948).

No information about the youngest or oldest seed-bearing age in speckled alder was found, and little is known about geographical differences in seed production. Other alder species bear seed when less than 10 years old and yield good seed crops almost every year. Winds spread the seeds during September through April. Spreading distances and the number of seeds produced per plant are not definitely known.

Alders reproduce from seeds, sprouts, layering, underground stems, and suckers. Seed is the primary source of new stands on freshly exposed soil. Perpetuation and spread of established stands result mostly from sprouting or other vegetative means.

Growth rates depend on many factors, including site conditions, competition, and type of growth (seedling or sprout). The largest speckled alder stand observed in a Michigan study was 26 years old and had stems averaging 5.5 inches d.b.h. and 25 feet tall (Brickman 1950). Clearcutting one aspen-balsam poplar-speckled alder stand in northern Michigan resulted in a dense stand of alder sprouts, which reached a maximum height of 6 feet the second year after cutting (Day 1956). Eight speckled alder stands in Ontario showed great

variation in height/age relationships among individual stems. The alder stands were growing on peat-covered clay soils and had originated after clearcutting black spruce. The tallest stem measured was 12 feet high and 13 years old, while the oldest was 30 years old and only 5.5 feet high. The average height of the speckled alder canopy varied from 3 to 6 feet, and the annual height growth declined steadily after 9 to 10 years of age (Vincent 1964).

Hazel alder stands in Pennsylvania had similar growth patterns. Stem growth was most vigorous from 1 to 8 years. Stems were more than 15 feet tall at 10 years of age, but height increased little during the next 10 years. After about 20 years of age, many stems began to die and few stems reached 30 years of age (Liscinsky 1972:36).

The alders are primary invaders of denuded areas with saturated soil. Both species grow more vigorously in full sunlight than in shade, and they are intolerant to intermediate in tolerance to shading. In general, sprouts are more tolerant of shade than seedlings (Brickman 1950) and speckled alder may be more tolerant than hazel alder.

Hazel alder stands in Pennsylvania seldom regenerate themselves, and they are usually replaced by trees (Liscinsky 1972). Speckled alder stands in northern Michigan are often overtapped by species such as balsam fir, northern white-cedar, and red maple, but it takes many years for these species to replace alder (Brickman 1950). In the same area, speckled alder is common beneath stands of tamarack, balsam poplar, aspen, and birch; and on some sites it may even replace aspen and balsam poplar (Brickman 1950). Speckled alder has been recommended for ornamental plantings in shady areas (Kammerer 1934).

USE BY WILDLIFE

Moose, muskrats, beavers, cottontails, and snowshoe hares feed on twigs and foliage. Deer browse alders, but most investigators rate the plant low in preference. Woodcock and grouse eat small quantities of buds, catkins, and seeds. Alder seeds are also eaten by some smaller birds, particularly redpolls and,

to a lesser extent, goldfinches (*Martin et al 1951*).

Alder is an important cover plant for woodcock and grouse. Woodcock use alder covers from early spring through fall for nesting, feeding, and resting. They prefer the edges more than centers of large evenage thickets (*Liscinsky 1965*). Alder stands were considered important grouse cover in Michigan, particularly where deer had eliminated other shrubs. Speckled alder provided the high shrub cover needed around grouse drumming sites (*Palmer 1963*). Beavers commonly use alders in dam construction.

PROPAGATION

It is usually best to collect and process local shrubs. Seed or seedling stock is seldom available commercially. Conelets can be harvested in September and October from standing or felled alders. Seeds are easily shaken out of dried conelets, but it is difficult to fan or screen out impurities (*U.S. Forest Service 1948*).

The following information pertains to hazel alder seeds gathered in Pennsylvania (*Liscinsky 1972:63*). When seed was plentiful it took 1 hour to pick 4 gallons of cones, which produced 1.6 pounds of seed (3.2 quarts). When seed was scarce, it took 1 hour to pick 1 gallon of cones, which yielded 0.4 pounds of seed. It took 2.5 gallons of cones to produce 1 pound of seed. Purity of seed ranged from 60 to 90 percent, and soundness ranged from 30 to 60 percent. Germination capacity varied from 2 to 60 percent. One pound of seed had a volume of 2 quarts and contained a total of 300,000 seeds.

The number of speckled alder seeds per pound is variable. Separate studies yield the ranges of 256,000 to 625,000 (*Van Dersal 1938*) and 473,000 to 890,000 (*U. S. Forest Service 1948*) seeds per pound. The latter group averaged 666,000 seeds per pound, 41 percent pure and 51 percent sound (*U. S. Forest Service 1948*). Yields of usable plants per pound of seed have been reported as 10,000 for speckled alder and 40,000 for hazel alder (*Van Dersal 1938*).

The easiest way to handle alder in the nurs-

ery is to sow fresh clean seed in November (*Heit 1968:15*). Seed should be broadcast or drilled in and lightly covered with either washed sand or sand mixed with hardwood humus. Either was superior to nursery soil or leaf litter for covering speckled alder seedbeds (*U. S. Forest Service 1948*). Seedbeds should be mulched for overwinter protection, but the mulch should be removed when germination begins in the spring. The beds should be kept moist and shaded until late summer of the first season (*U. S. Forest Service 1948*).

Seed may be planted in the spring if it is first stratified in moist sand or vermiculite for 60 to 90 days. Speckled alder seeds stratified for 2 months at 32 to 40° F. gave excellent germination within 10 days after sowing (*Daly 1966*). Hazel alder seeds stored at 41° F. for 206 days gave 30 percent germination, which was mostly complete 10 days after sowing. Keeping the seeds in complete darkness had no effect on percent or time of germination (*McDermott 1953*).

For long-term storage, seeds should be thoroughly cleaned, air-dried and refrigerated in sealed containers. Alder seeds kept in this manner at 34 to 38° F. were viable after 10 years (*Heit 1967e*).

Two- and 3-year-old seedlings should be used for field plantings; 1-year-old hazel alder stock had very low average survival in the field (*Liscinsky 1972:61*). Plantings succeeded on a variety of sites, but not on extremely dry soil. Heavy sod should be scalped back before planting; competition from dense herbaceous vegetation can cause planting failures.

Direct seeding of hazel alder in the field has been successful in Pennsylvania (*Liscinsky 1965, 1972*). Seedbeds prepared by disking produced 35 percent more seedlings than untreated plots, but good catches occurred even when seed was sown directly on sod. Cool, moist sites were best for direct seeding, and the sites closest to the stream produced the most seedlings. Generally, the best results were obtained when fall-collected seed was sown during the following February and March. Seeding rates were about $\frac{1}{2}$ pint ($\frac{1}{8}$ pound) per 100 square feet. Attempts to propagate hazel alder in the field from stem and root cuttings were unsuccessful (*Liscinsky 1972:61*).

MANAGEMENT

Alders, along with other desirable species, are good for reforesting various kinds of spoil banks. Alders are also ideal as streambank cover and for increasing the fertility of bottomlands. Fertility increase is from nitrogen-fixation by root nodules and from fallen leaves. The amount of nitrogen added to the soil varies, but in general the alders compare favorably with legume crops and black locust (*Daly 1966, Lawrence 1958, Lowry et al 1967*). European foresters plant alders beneath conifers to increase soil nitrogen and stimulate the growth of crop trees.

Alder stands can be established by planting seedlings or by direct-seeding on cool, moist sites. Where alders are present but suppressed, fire and most logging practices favor alder over competing species. Large stands of alders commonly form after spruce and fir are logged from wet ground.

Large stands are probably best managed for wildlife on a rotation of 30 years or less, based

on the time the alders require to reach maturity or grow so tall that they handicap hunters. Cutting schemes should provide patches of various age classes, well dispersed throughout the stand. A cutting cycle of approximately 25 years, with cutting at 4- to 5-year intervals, has been recommended for managing alder coverts for woodcock in Pennsylvania (*Liscinsky 1972*).

Overmature thickets can be opened up by clearcutting. Spring and winter cutting will result in the most rapid sprout growth; July and August cutting will produce the thinnest stands and least height growth (*Brickman 1950*). Stands overtopped by larger trees respond well to release cutting, but stumps of pole-size hardwoods should be poisoned to reduce sprouting. Competition from tree seedlings, particularly conifers, should not limit stump sprouting of alders.

Several formulations of the herbicides 2,4,5-T and 2,4-D effectively control alders when applied as stump, basal, or foliage sprays (*Liscinsky, personal communication*).

AMERICAN BITTERSWEET

Celastrus scandens L.

Also called Climbing, False, or Shrubby Bittersweet; and Waxwork.

By Jack I. Cromer

West Virginia Department of Natural Resources
Elkins

RANGE

American bittersweet occurs from southern Quebec to southern Manitoba and southward to Georgia, Alabama, Louisiana, Oklahoma, Texas, and New Mexico.

HABITAT

This vine grows under a diversity of climatic conditions, but no information about climatic optima or limits was found.

It is common along stream banks, in old fields, in low thickets, and in fencerows. It tolerates a variety of soil textures (sand, loam, and clay), but prefers soils with a nearly neutral pH (Wherry 1957). It grows well in partial shade or full sunlight, but best in sunny locations, either on banks or where the vines can ascend a supporting structure (Holweg 1964, Hosley 1938).

Associated plants in Minnesota were moonseed (*Menispermum canadense*), frost grape (*Vitis* spp.), and prickly ash (*Xanthoxylum americanum*) (Daubenmire 1936); and in Missouri redbud (*Cercis canadensis*), herbaceous mandrake (*Podophyllum peltatum*), goosegrass (*Eleusine indica*), and Miami-mist (*Phacelia purshii*) (Shelford 1963).

LIFE HISTORY

Greenish-yellow flowers appear in late May and June. On individual plants, flowers are mostly unisexual. The primarily female-flower plants usually have enough male flowers for fertilization (Hosley 1938), but plants of both sexes should be fairly close together to insure good fruiting (Holweg 1964). Fruits ripen in September and October; some may persist on the plants as late as March, although most drop before late winter (Petrides 1942).

Seed production starts at 3 years in vigorous plants growing in full sunlight (Spinner and Ostrom 1945), but may be delayed a year or longer in less vigorous plants. Good seed crops are commonly produced each year.

Bittersweet may reproduce by layering or from stolons.

Growth rate of plantings is variable; in Vermont, Delaware, and West Virginia, average lengths of 7-year-old stems ranged from 15 inches to 12 feet. Generally, stem growth averaged 12 to 30 inches in 3 years, 30 to 60 inches in 5 years, and about 6 feet in 7 years, with little additional growth afterwards (Edminster and May 1951).

On good sites, bittersweet is aggressive and competes well with other vegetation. However,

plantings along pasture fences are commonly browsed back to stubs whenever they are within reach of cattle (*Edminster and May 1951*). Plantings in New York were also retarded by browsing deer (*Smith 1962*) and rabbits (*Petrides 1942*).

USE BY WILDLIFE

Fruits, buds, and leaves are potential food for ruffed grouse, pheasants, quail, wild turkeys, and other birds. Rabbits and squirrels relish the fruits; rabbits and deer eat the leaves and stems.

The twining vines form excellent wildlife cover. Bittersweet, along with wild grape and elderberry, provides outstandingly acceptable nesting sites for hedgerow birds (*Petrides 1942*).

PROPAGATION

Bittersweet can be propagated easily from cuttings of mature shoots, layerings, or roots (*Fuller 1910*). Female plants are preferred as stock. Root cuttings, either softwood in summer or hardwood in fall and winter, have been used successfully (*Hosely 1938*).

Seeds can be collected in mid-September and later, as long as the fruit capsules hang on. They should be spread out and allowed to air-dry for 2 or 3 weeks. Cleaned seeds average 26,000 per pound (12,000 to 40,000). Average purity of commercial seed was 93 to 98 percent and soundness was about 84 percent (*U. S. Forest Service 1948*).

Seed dormancy is broken by pre-chilling for 2 to 6 months. Stratification in moist sand or peat for 90 days at 41°F. is recommended (*Barton 1939*). Seeds stored in a cool-damp basement gave no germination after 1 year, but seeds that had been air-dried and stored in sealed glass containers at 34 to 38°F. re-

tained excellent germination capacity after 4 to 8 years (*Heit 1967e*).

If stratification is impractical, seeds can be sown in the fall; however, emerging seedlings are susceptible to decay by soil-inhabiting fungi. For outplanting, 2-year-old seedlings are apparently best. At each planting site, all competing vegetation should be removed from at least 1 square foot (*Edminster and May 1951*) around the plant.

MANAGEMENT

Aside from having food and cover value for wildlife, bittersweet is a desirable ornamental and can also be used to control erosion. The fall leaf color is yellow, and the persistent orange fruits add attractive color to landscapes during fall and early winter. This species is especially well adapted for training over out-buildings and for climbing over walls, trellises, trees, and shrubs (*Hosley 1938*).

Plantings have generally survived well, and they spread by runners; but growth and fruit production have often been retarded by rabbit and deer browsing (*Smith 1962*). The high palatability of this plant requires caution in selection of planting sites. The best use of bittersweet may be as a filler among plantings or natural growths of other shrub species (*Edminster and May 1951*).

Aggressiveness of bittersweet should also be considered, because rapid spread on exceptionally favorable sites may lead to control problems. No specific information about control methods was found.

MISCELLANY

The fruiting branches are valuable for commercial use or as home decorations; however, bittersweet fruits are thought to be poisonous if eaten by humans (*Grimm 1952*).

BLUEBERRIES

LOWBUSH BLUEBERRY, *Vaccinium angustifolium* Ait. Also called Lowsweet, Dwarf or Sugar Blueberry, Sweethurts, and Strawberry-Huckleberry.

Highbush blueberry, *Vaccinium corymbosum* L. Also called Tall or Swamp Blueberry, Wortleberry, and Seedy Dewberry.

By Robert Rogers

Rutgers University
The State University of New Jersey
New Brunswick

RANGE

Lowbush blueberry, the more northerly species, occurs from the tundra in Canada, throughout the New England States, in the Piedmont and mountain areas of Pennsylvania and New Jersey, and south down the Appalachian Mountains to northern Virginia (Darrow and Moore 1966). Highbush blueberry occurs along the Atlantic Coast from eastern Maine to northern Florida and also in the Great Lakes region, including northern Indiana, northern Ohio, northwestern Pennsylvania, southern Wisconsin, and southern Ontario (Darrow and Moore 1966).

HABITAT

Both species are acclimated to climatic extremes in the southern part of the region. In the northern part of the region, growth of highbush blueberry is limited by growing season and extreme winter temperatures. A minimum adequate growing season of 160 days is required for highbush blueberry (Chandler

1943). Temperatures below -20°F result in winter-kill, and temperatures below -30°F will kill plants to ground or snow level (Cain and Slatke 1953). Although lowbush blueberries border the tundra in Canada, they are favored by a minimum growing season of 125 days (Chandler 1943). Lowbush blueberry is found farther north than highbush blueberry, perhaps because its prostrate form accommodates it to a protective snow cover (Eaton 1949). Summer temperatures in excess of 120°F can cause mortality in young plants (Kender and Brightwell 1966).

Blueberries, like most members of the Heath family, prefer acid soil. They make their best growth on light, well-drained acidic soils high in organic-matter content (Kender and Brightwell 1966, Van Dersal 1938). Soils developed from limestone are not conducive to good blueberry growth.

Lowbush blueberry is the typical upland blueberry in the Appalachian Mountain areas from West Virginia north to the New England States. Stony, silt, and clay loam soils devel-

oped from sandstones, shales, and glacial drift commonly support colonies of lowbush blueberry. These colonies often occur on dry, rocky, open upper slopes and ridgetops (Braun 1950, Fernald 1950, Darrow and Moore 1966, Van Dersal 1938).

Highbush blueberry is frequently found at lower elevations along the Atlantic Coast and in the Great Lakes region, where it occurs along the edges of swamps, within open areas of moist woodlands, and occasionally in moist upland fields (Fernald 1950, Darrow and Moore 1966). Highbush blueberries grow: on soils consisting of sandy loams developed on Coastal Plain sands and clays in Maryland, Delaware, southern New Jersey, Long Island, and southeastern Massachusetts; sands and loamy sands developed on glacial drift; and on stony and gravelly silt and clay loams developed on glacial drift, which frequently have a hardpan in the soil profile (Beckwith and Coville 1931, Johnston 1942, Trevett 1962, Van Dersal 1938).

Heavy soils with poor drainage prevent root penetration and thereby increase the probability of frost heaving; and coarse sandy soils present droughty conditions during summer months despite normal rainfall. During dry periods, blueberries are hindered in water uptake because they lack root hairs (Ballinger 1966, Kender and Brightwell 1966). Optimum growth of blueberry occurs when soil pH is between 4.3 and 4.8 (Kender and Brightwell 1966). However, blueberries are commonly found on soils having pH values ranging from 3.5 to 5.5, although soil pH values higher than 5.2 seem to limit growth (Ballinger 1966).

Blueberries are relatively intolerant to shade, and tend to flourish in open areas. Shading reduces vegetative growth and flower-bud formation in both species (Hall 1958, Reiners 1967). Throughout the region, both species are found in association with other members of the Heath family, especially mountain laurel, huckleberry, and azalea. On moist sites along the Atlantic Coast, highbush blueberry may grow with alder, gray birch, blackhaw, arrowwood, silky dogwood, and red and black chokeberry. It may be succeeded by red maple, blackgum, ash, sweetgum, elm, yellow-poplar, pin oak, white oak, black oak, and

shagbark and mockernut hickories. The chief shrub competitor of lowbush blueberry in the northern forest is mountain laurel (Hall 1963, Shelford 1963). Invasion of the shrub layer by pioneer tree species rapidly reduces the abundance of lowbush blueberry (Shelford 1963).

LIFE HISTORY

Blueberry flowers appear with the leaves in spring. Flower buds are formed during the previous season, and the pinkish-white bell-shaped flowers are arranged in elongated clusters (Eck 1966, Gleason 1963b, Shutak and Marucci 1966). Insects, specifically wild and honey bees, are the chief pollinating agents of highbush and lowbush blueberries. Both fruit yield and fruit size are a function of the bee population in a given area (Martin 1966; Marucci 1966; Shutak and Marucci 1966). Highbush blueberry fruit matures from 50 to 90 days after bloom, while lowbush blueberries mature from 90 to 120 days after bloom. Lowbush blueberry flowers from April to June. The fruit is available from July to September (Van Dersal 1938). Highbush blueberry flowers from May to June, and the fruit is available from June to August (Kender and Brightwell 1966, Van Dersal 1938).

Highbush blueberry plants bear fruit when 8 to 10 years old, but some plants may bear fruit as early as the third year (Taylor 1962). An established mature bush can be expected to yield 8 to 10 pints of fruit per year; however, fruit production may vary with local conditions (Taylor 1962). Fruit yield of lowbush blueberry is usually lower than that of highbush blueberry because of relatively poor blossom set. This reduced ability to set blossoms is attributed to various degrees of self-sterility in large clones (Aalders and Hall 1961). Also, velvet-leaf blueberry pollen is incompatible with lowbush pollen. If velvet-leaf blueberry (*V. myrtilloides* Michx.) is present in the stand, lowbush pollen will be diluted and fruit production will be reduced (Aalders and Hall 1961).

Blueberries reproduce from seeds, sprouts, underground stems, and suckers. Seed is disseminated chiefly by animals, from June through September. On sites previously uninhabited by blueberry plants, seedlings become

established in open areas on exposed mineral soils. Highbush blueberries are usually crown-forming plants 6 to 15 feet high, which may consist of several stems. Individual plants sometimes tend to sucker at the base and form extensive colonies. Lowbush blueberries may form extensive colonies by means of underground stems (Camp 1945). Growth of both species is comparatively slow even on the best sites. Highbush blueberry will attain a height of 6 to 15 feet in 8 to 10 years (Taylor 1962). I found no growth-rate figures for lowbush blueberry. The maximum height growth for lowbush blueberry is about 2 feet.

Both species are intolerant to shade and are found in open woods or clearings. Encroachment by shade-tolerant species restricts blueberries to openings in the stand or quickly relegates them to suppression and eventual elimination if no openings are provided. After fire or logging, lowbush blueberry will become reestablished from roots within the area (Hall 1955).

USE BY WILDLIFE

Blueberries are important to American wildlife (Martin *et al* 1951). For several species of grouse, blueberries are among the most important summer and early fall foods. They also are part of the diet of other upland game birds such as bobwhite, wild turkey, and mourning dove. Many song birds, including the scarlet tanager, bluebird, and thrush, also feed on blueberries. Fur and game mammals such as the black bear, red fox, cottontail rabbit, eastern and spotted skunk, and the fox squirrel utilize the fruit, twigs, and foliage of the blueberry. Part of the diet of the white-footed mouse consists of blueberry fruit. White-tailed deer browse the branches and foliage and eat the fruit (Martin *et al* 1951; Van Dersal 1938). Because of the dense shrubby growth often produced by highbush blueberry, and its high food value, it can be a desirable hedgerow plant, providing both food and cover for a variety of song birds, ruffed grouse, and cottontail rabbit.

PROPAGATION

Seed and stock are available commercially for highbush blueberry, but are not commonly available for lowbush blueberry. Highbush blueberries are commonly propagated by hardwood cuttings obtained from healthy shoots of the past season's growth, $\frac{1}{4}$ -inch diameter or less. Shoots are gathered in the spring just before bud growth starts—15 March to 10 April in New Jersey (Doehlert 1953). Fruit buds are undesirable on shoots used for cuttings and should be rubbed off if present (Mainland 1966). Shoots should be cut into pieces 3 to 5 inches long, using either a sharp knife or pruning shears. The cut is usually made below the bud for small quantities of twigs, but for large quantities a bench saw is used and bud position is ignored.

The cuttings should be treated with a fungicide and set in either a box frame, solar frame, or open frame containing an equal mixture of sand and horticultural peat (Doehlert 1935). About 75 percent of the cuttings should root. Rooting has taken place when the terminal bud begins to green. Liquid fertilizer (either 15-30-4 or 13-26-13, at 1 ounce of concentrate per 2 gallons of water) can be applied to rooted cuttings during the summer, but its use should be discontinued in time to allow adequate tissue hardening—mid-August in New Jersey (Doehlert 1953). Young plants can be left in the propagating beds over winter, or they can be transplanted into nursery beds in early fall to allow adequate root growth before winter.

Seeds are commonly used to propagate lowbush blueberry; this method may also be used to propagate highbush blueberry. Berries should be collected when ripe, and chilled at 50°F for several days. Seeds can be removed from the berry by shredding in a food blender for 30 seconds (Morrow *et al* 1954). Sound seeds will settle to the bottom. Stratification may be beneficial in hastening germination. Seeds should be planted in a mixture of sand and horticultural peat. Seedlings will begin to emerge in a month and will continue to emerge for a long period thereafter. Seedlings can be transplanted to other flats after they are 6 to 7 weeks old. Seed may be kept under normal refrigeration and will remain viable for

as long as 12 years (*Darrow and Scott 1954*).

Young highbush blueberry plants can be transplanted into the field after the first season. Spacing between plants ranges from 4 to 8 feet between plants and 8 feet between rows. Lowbush blueberries may be established in barren areas by using a golf-hole cutter to remove sod containing roots from a vigorous stand and transplanting it to the desired area (*Hitz 1949, Eggert 1955*). The distance between holes should be no more than 8 inches. Blueberries are exacting in their site requirements and attempts at establishment on less favorable sites have been disappointing (*Kender and Brightwell 1966*). If blueberries are present naturally, in most situations a desirable stand can be cultured.

MANAGEMENT

Lowbush blueberries are often found in the undergrowth of open forest stands in a suppressed stage in which they rarely flower and bear fruit. Removal of competing vegetation

will stimulate the blueberry's root system and increase the vigor, abundance, and fruit yields of the plants (*Hall 1955, 1963*). For maximum flowering and fruiting of blueberries, competing vegetation should be reduced to a minimum. This can be accomplished by shallow cultivation or, in the case of lowbush blueberries, light burning in the spring once every 2 or 3 years (*Chandler 1943, Shutak and Marucci 1966*). Care must be taken to avoid fires hot enough to destroy the roots from which new shoots will appear. Pruning is beneficial to both species because fruit is borne abundantly on 1-year shoots rather than on old mature branches.

When enlarging a field from an adjoining woodland, it is advisable to clear the land slowly by cutting and burning a strip 2 or 3 feet wide each year. The overstory must be removed gradually over a period of several years (*Hall 1955*). The herbicides 2,4-D and 2,4,5-T applied on foliage, stems, or stumps will control blueberries.

BRAMBLES

Also called Blackberry, Dewberry, Groundberry, and Raspberry.

ALLEGHENY BLACKBERRY, *Rubus allegheniensis* Porter

BLACKCAP RASPBERRY, *Rubus occidentalis* L.

CANADIAN or THORNLESS BLACKBERRY, *Rubus canadensis* L.

FLOWERING RASPBERRY, *Rubus odoratus* L.

NORTHERN DEWBERRY, *Rubus flagellaris* Willd.

RED RASPBERRY, *Rubus strigosus* Michx.

SWAMP GROUNDBERRY, *Rubus hispida* L.

By Earl L. Core

*West Virginia University
Morgantown*

SPECIES

No one knows how many kinds of brambles there are in eastern North America, but more than 500 have been named. Classification of the brambles has been thoroughly treated in other publications (*Bailey 1941-45; Bailey 1947; Bailey 1949; Davis et al 1967-70*).

Blackberries have erect stems, usually angled in cross-section, and armed with large sharp spines. There are usually five leaflets. Dewberries and groundberries have prostrate, trailing stems. Raspberries have erect canes, usually white-powdered, round in cross-section, and often without spines or with weak hairlike spines. There are usually three leaflets. Also, in raspberries the fruit is thimble-like or cap-like, the dry receptacle remaining

on the bush; while in blackberries the receptacle itself becomes fleshy and is removed with the fruit.

RANGE

Brambles are found throughout the Northeast. Those listed above are common and widespread, but many other important species occur (*Davis and Davis 1953, Fernald 1950, Strausbaugh and Core 1953*). Red raspberry, Canadian blackberry, swamp groundberry, and northern dewberry are common in the higher elevations and northward, while Allegheny blackberry, blackcap raspberry, and flowering raspberry are more abundant at lower elevations and latitudes (*Shelford 1963*).

HABITAT

Typically the brambles are plants of old fields and woodland clearings. The various species are acclimated to practically all the extremes that occur in the Northeast.

Brambles grow well in a great variety of soils and topographic conditions. Red raspberry is frequent in acid barrens at the higher elevations, where it grows with other acid-loving plants such as blueberries, huckleberries, menziesia, azaleas, mountain laurel, great laurel, and teaberry. Swamp groundberry is widespread in mountainous areas in low boggy places or upland mossy lands. It is associated with cranberries in sphagnum bogs or with teaberry and other plants in mossy uplands.

There are numerous other similar species of groundberries. Northern dewberry is most common northward, but despite its name, ranges south to Georgia, trailing in dry fields and along road banks.

Blackberries generally occupy an intermediate temporary stage in old fields, associated with hawthorns, crabapples, sassafras, fire cherry, black cherry, and other pioneer trees. They are quickly eliminated as overgrowing trees provide too much shade. Allegheny blackberry and many other blackberries are common in dry places from lowlands to uplands, open places in woodlands, along roadsides, in old fields, fence-rows, clearings, and thickets. Canadian blackberry, one of the taller and later-flowering species, is very common in woods, old fields, cool hollows, and along roadsides, mostly in the mountainous regions.

Flowering raspberry is abundant in shady places in woods, along roads and in thickets. Blackcap raspberry is common in woods, borders, fields, fence-rows, and thickets. It is often associated with black walnut trees, a situation unfavorable to many plants. In a study of succession on abandoned farm fields in southern Illinois, blackcap raspberry first appeared 3 years after abandonment and was still present after 40 years. It remained important as long as fields were open and decreased with the increase of woody vegetation. Sassafras, persimmon, and winged sumac were among the first woody invaders (Bazzaz 1968).

LIFE HISTORY

Brambles are perennial; in most species the root lives for many years and the stems live for only 2 years. First-year stems are usually sterile and have leaves unlike those of the second year. Flowers and fruit are borne the second year. In most species, flowers appear in May and June, and fruits are ripe in early summer. In the Canadian blackberry, however, ripe fruits persist into September. No figures on seed production per plant were noted. The seeds are spread mostly by birds.

Brambles reproduce from seeds, sprouts, layers, and underground stems. Vegetative propagation is the primary source of development of the dense colonies often seen in old fields. New colonies on freshly exposed areas develop from seeds. Growth of most brambles is more vigorous in full sunlight than in shade. Blackberries grown in shade are often nearly or quite thornless, but produce few fruits. In full sunlight the thornless habit disappears, but fruit production is greatly enhanced. Raspberries, in contrast, seem to do better in partial shade. In the Southeast their habitat preference often puts the brambles in direct competition with Japanese honeysuckle.

USE BY WILDLIFE

Blackberries and raspberries stand at the top of summer foods for wildlife. Even dried berries persisting on the canes are eaten to some extent into fall or early winter; the principal use, however, is while the fruits are juicy. Nearly all species are palatable to human tastes, and probably are equally so to wildlife (Chapman 1947d). Another important factor is the widespread availability of brambles in all parts of the Northeast—indeed, in nearly all parts of the United States and Canada.

Birds are especially prominent as users of the fruits. Blackberries and raspberries are important to game birds such as grouse, ring-necked pheasant, and bobwhite quail, and to such common songbirds as catbird, cardinal, yellow-breasted chat, pine grosbeak, robin, orchard oriole, summer tanager, brown thrasher, thrushes, and towhees. Blackberry and raspberry fruits are also important foods of raccoons, chipmunks, and squirrels, as well as

other small animals. Deer and rabbits make extensive use of leaves and stems (*Martin et al 1951*).

Because of their habit of forming extensive colonies the various species of brambles have much value as cover for wildlife. The thorny canes create nearly impenetrable thickets where birds, rabbits, and other animals find relative security. In winter, rabbits nibble the stems while at the same time finding security from enemies. Colonies of brambles are common nesting sites for small birds (*Martin et al 1951*).

PROPAGATION

Horticultural varieties of blackberry and raspberry are readily available from nurseries. Dewberry or groundberry stock is also available, although less readily. Since commercial culture is usually for fruit production, nurseries propagate brambles vegetatively from tip layers, root cuttings, and suckers.

Brambles tolerate a wide range of soil types, textures, and pH values; but adequate soil moisture is critical for fruit production. Commercial stands produce best on deep sandy loam with a large supply of humus. Transplanting is done during the dormant season, usually in early spring, and transplanting after growth has started is avoided. Growing stock, propagated in any manner, is generally cut back to ground level when transplanted (*Mecartney 1945, Darrow and Waldo 1948*).

Tip layering is a simple, naturally occurring process recommended for raspberries (*Mecartney 1945*). Raspberry canes grow so that by late August or September the tips reach the ground, and many of these will form new plants naturally. To insure large numbers of new plants, cane tips should be set 4 to 6 inches straight down into the ground, and the soil should be formed around them. Canes are ready for layering when the tips have elongated so that a bare portion extends 3 to 6 inches beyond the last small set of leaves. Rooting will begin in about a week, and rooted tips can be cut from the parent plant and transplanted the next spring (*Darrow and Waldo 1948*).

Blackberries send up suckers, and new plants are usually obtained by digging and

transplanting these suckers (*Mecartney 1945, Darrow and Waldo 1948*). Root cuttings provide another simple method of propagating blackberries. Roots $\frac{1}{4}$ inch or more in diameter are dug in the fall or early spring, and divided into pieces 3 inches long. These are planted horizontally in trenches about 3 inches deep, and by the following fall new plants will have developed (*Darrow and Waldo 1948*).

Brambles can be propagated from seed in the field or nursery. Blackberry seeds have extremely hard coats. Untreated seeds germinated over a period of 3 to 5 years, with very little germination the first year (*Heit 1967b*). To obtain maximum germination the first year, the seeds must be treated so that water can penetrate the coat. Cleaned seed should be soaked in concentrated sulphuric acid for 50 to 60 minutes at 75 to 80°F (*Heit 1967a*). Shorter treatments are less effective and longer ones will cause injury. Seeds should be thoroughly washed immediately after acid soaking, and planted in late August or early September. In nurseries seeds are sown on peat moss or light soil; in the field they should be sown on mineral soil.

Raspberries do not have the extreme hard seedcoat of blackberries. A long warm-and-cold stratification period will usually give good germination, and fresh cleaned seed may be sown in late summer. However, better and more uniform germination can be obtained if raspberry seeds are given a 10- to 30-minute sulphuric acid treatment before sowing in late summer (*Heit 1967, pt. 7*). Treated blackberry and raspberry seeds may be planted in early spring, but they require a 1- to 3-month cold stratification period at 34 to 38°F. This stratification treatment is recommended for seeds of all brambles that are to be spring-planted (*Heit 1967b*).

MANAGEMENT

Besides providing food and cover for wildlife, brambles have great erosion-control value. Many species form dense thickets rapidly, and some form dense mats on the ground. Most species grow satisfactorily in very barren and infertile soils; and they invade and rapidly occupy burns, eroded areas, old fields, and

logged areas (*Barrett, Farnsworth, and Rutherford 1962; Van Dersal 1938*). Because there are so many species and they are so abundant, it is seldom necessary to establish brambles. Direct-seeding would be justified if it were important to establish cover quickly or to insure development of the desired species in a new opening.

Openings are the key to managing bramble patches, because invading trees and shrubs quickly eliminate most brambles. Bramble patches can be encouraged or rejuvenated by removing overhead shade, mowing, light burn-

ing, or deep cultivation. Mowing and burning stimulate sprouting in addition to removing competing vegetation. Deep cultivation (6 to 9 inches) cuts the roots of existing brambles, and causes the formation of large numbers of sucker plants.

Benzabor (disodium tetraborate pentahydrate 54.50 percent and disodium tetraborate decahydrate 35.5 percent with trichlorobenzoic acid 8 percent), applied with hand-operated mechanical spreaders or blast guns in early spring and summer, is effective against brambles (*Waestemeyer 1963*).

CHECKERBERRY WINTERGREEN

Gaultheria procumbens L.

Also called Checkerberry, Grouse Berry, Mountain Tea, Partridge Berry, Teaberry, Winterberry, Wintergreen, and many other common names (*Krochmal et al 1969*).

By Sadie L. Robinette

West Virginia University
Morgantown

RANGE

Checkerberry wintergreen or teaberry occurs from Newfoundland to Manitoba south to Virginia, Kentucky, and Minnesota, and in the mountains to Georgia (*Gleason 1963c*).

HABITAT

Checkerberry wintergreen is hardy throughout the Northeast. It requires acid soil and usually grows within the pH range of 4.0 to 6.0 (*Wherry 1920 and 1957*). In a mature beech-maple forest in Ohio, checkerberry wintergreen was found growing where the pH of the soil ranged from 3.5 to 6.9 on the surface to 4.0 to 6.9 below the surface. Its distribution was independent of pH value within these ranges (*Stone 1944*). However, a pH of 4.5 to 6.0 has been reported as optimum for the growth of checkerberry wintergreen, with 7.0 the maximum pH it will tolerate (*Spurway 1941*).

As long as the soil is acidic, checkerberry wintergreen will grow well on many soil types, including peat, sand, sandy loam, and coal spoil banks. It will tolerate site conditions ranging from dry to poorly drained (*Wilde 1933*).

Checkerberry wintergreen is commonly found in heath shrub communities that are characteristic beneath many forest types, including both pine and hardwoods in New England, and jack pine and spruce-larch forests in the Lake States (*Braun 1950, Hosley 1938, Kittredge 1934*). It also occurs in bogs and as an invader of old fields in many parts of the region (*Strausbaugh and Core 1958:708*). Mountain-laurel, rhododendron, azaleas, blueberries, huckleberries, and trailing arbutus are the most common heath associates of checkerberry wintergreen.

In Maine, checkerberry wintergreen is abundant in grouse coverts in both upland and lowland hardwoods and mixed hardwood-conifer stands. The tree associates are yellow birch, sugar maple, beech, white birch, aspen, and spruce; and the ground cover associates include bunchberry, clover, partridgeberry, celandine, and shinleaf (*Brown 1946*). In Massachusetts, checkerberry wintergreen colonized abandoned farmland along with common juniper, flowering raspberry, and sumacs (*Hosley and Ziebarth 1935*). It also volunteered on coal spoil banks in central Pennsylvania, where it formed part of the shrub layer beneath aspen-fire cherry stands. The common

shrubs growing with it were sweetfern, Allegheny blackberry, smooth and staghorn sumac, and prairie willow (Bramble and Ashley 1955).

LIFE HISTORY

Checkerberry wintergreen's small, white, perfect flowers are borne from June to September. The bright red fruit ripens in the fall, and often remains on the plant until early the next summer (U. S. Forest Service 1948:187). The fruit is rather dry and consists of fleshy flower parts surrounding a dry capsule, which contains many minute seeds (U. S. Forest Service 1948). There are approximately 2,800 fresh fruits per pound, and about 3,000 dried fruits per pound (Swingle 1939, U. S. Forest Service 1948, Van Dersal 1938). Individual plants usually bear 2 to 6 berries.

I found no information concerning the longevity of this perennial plant, or the age at which it first produces fruit. The growth rate is slow, and there is little hazard of spreading from planted specimens (Ruffner 1965).

Checkerberry wintergreen reproduces vegetatively from root suckers (Hosley 1938). Seeds are probably the source of new plants colonizing old fields, and birds may disseminate the seeds.

Checkerberry wintergreen is shade-tolerant, but most fruiting occurs in openings (Edminster 1947:120). Heavy fruiting often follows cutting of timber (Hosley 1938).

USE BY WILDLIFE

Checkerberry wintergreen is not taken in large quantities by any species of wildlife, but the regularity of use enhances its importance (Edminster 1947, Martin et al 1951). It is a year-round fruit producer, and one of the few sources of green leaves in winter (Brown 1946, McAtee 1914).

White-tailed deer and ruffed grouse are the most important users of checkerberry wintergreen. Grouse eat both fruit and leaves throughout the year, and in some localities teaberry is one of the most important grouse foods (Brown 1946, Edminster 1947, Hosley 1938). White-tailed deer browse teaberry throughout the region, and in some localities

it is an important winter food (Hosley and Ziebarth 1933, Watts 1964).

Other animals that eat checkerberry wintergreen are wild turkey, sharp-tailed grouse, bobwhite quail, ring-necked pheasant, black bear, white-footed mouse, and red fox (Hosley 1938, Martin et al. 1951, Van Dersal 1938). Teaberries are a favorite food of the eastern chipmunk, and the leaves are a minor winter food of the gray squirrel in Virginia (Duderer 1967, Van Dersal 1938).

PROPAGATION

Checkerberry wintergreen has been cultivated at various times in the past, but seed and growing stock are not usually available from nurseries (Rehder 1940:739). Commercial seed consists of the dried fruits, which number about 3,000 per pound. Seed may be collected locally at any time in the fall after ripening (usually early September). Seed is extracted by drying the fruit until it is brittle and powdery and then rubbing it through a 30-mesh screen (U. S. Forest Service 1948). The number of clean seeds per pound has been reported as 163,000 and 2,870,000 to 4,840,000 (Swingle 1938, U. S. Forest Service 1948).

The seed has a dormant embryo, so it must be either planted in the fall or stratified before spring planting. Probably the easiest way to propagate small quantities of teaberry is by sowing whole fruits soon after collection in the fall. Fruits should be sown outdoors in moist, acid soil in a shady location. Seedbeds should be protected from rodents over winter.

For spring planting, seed should be cleaned soon after collection, and then stratified for 30 to 75 days at 41°F before planting. Because of its minute size, clean seed should be scattered on or pressed into peat, and then protected with a pane of glass placed about 4 inches above the soil. Seedbeds should be shaded. The soil should be moist, porous, and acidic; mixtures of sand and peat are usually used (U. S. Forest Service 1948).

Checkerberry wintergreen can be propagated at any time during the spring and summer by simple layering. It reproduces vegetatively from root suckers, and new plants may be obtained during the spring or fall by digging and transplanting suckers. Clumps of

checkerberry wintergreen can also be divided and transplanted during the spring or fall (*Bailey 1950, Laurie and Chadwick 1931*).

Establishment in the field should be limited to acid sites, and plants will do best in partial shade.

MANAGEMENT

Checkerberry wintergreen is ordinarily plentiful in the woodlands of the Northeast, and no special care is needed to keep it growing (*Hosley 1938*). Fruit production can be stimulated by thinning timber stands and removing overtopping vegetation.

Checkerberry wintergreen is recommended to the suburban gardener as an ornamental and for attracting songbirds (*Mason 1945, McAtee 1914 and 1936*). It can be planted

under taller shrubs and in other partially shaded acid sites. Attractive groups of ground cover plants can be formed from checkerberry wintergreen, partridgeberry (*Mitchella repens*), bearberry (*Arctostaphylos uva-ursi*), bunchberry (*Cornus canadensis*), and Canada beadrush (*Maianthemum canadense*) (*Mason 1945*). Song birds will eat the fruits year-round, particularly during winter when few other fruits are available.

Checkerberry wintergreen was controlled by droplet spraying of the foliage with D-T, an equal mixture of 2,4-D and 2,4,5-T. A D-T mixture was more effective than 2,4-D alone. A 0.25-percent concentration of D-T killed checkerberry early in the growing season, but a 0.5-percent solution was more effective later in the summer (*Egler 1949*).

CHERRIES

COMMON CHOKECHERRY, *Prunus virginiana* L. Also called Black Chokeberry or Chokeberry, Cabinet Cherry, California Chokecherry, Caupulin, Cerisier, Chokecherry, Eastern Chokecherry, Rum Chokecherry, Western Chokecherry, Whiskey Chokecherry, and Wild Black Cherry.

By James R. Vilkitis

*University of Massachusetts
Amherst*

RANGE

Chokecherry grows from the Arctic Circle to Mexico and is one of the most widely distributed shrubs or small trees of North America. It occurs from Newfoundland and eastern Quebec across the continent to British Columbia, south to California, Arizona, New Mexico, Kansas, Missouri, Illinois, Indiana, Maryland, and Maine, and also southward in the Appalachians to parts of Kentucky, Virginia, North Carolina, and Georgia (Little 1953). In the mountains, in West Virginia at least, chokecherry has a scattered distribution (Strausbaugh and Core 1952-64).

HABITAT

Chokecherry is a hardy plant that, once established, defies northern extremes of climate. It occupies adverse sites such as moving sand dunes (Schlatzer 1964) and frost pockets where temperatures drop to 40°F below zero (Harlow 1957).

Occurring commonly in almost all soils of the Northeast, chokecherry can be found in a wide variety of habitats, from rocky hills and sand dunes to borders of swamps. It is even

found on the spurs of Mt. Katahdin, Maine, at an elevation of 4,000 feet (Mathews 1915). Chokecherry sometimes occurs in open woodlands, but it is more often associated with old fields, fence rows, roadsides, river banks, forest margins, and waste-corner thickets of farms. The species grows best in rich, well-drained, moist soil with ample sunlight, but it is also found in the shade on poor, dry soils (Van Dersal 1938). Optimum soil pH was reported as 6.0 to 8.0 (Spurway 1941).

Throughout its entire range, chokecherry is found in nearly all wooded areas (Harlow 1957, Rogers 1906). In the moving, slightly acid sand dunes it is a pioneer species associated with *P. besseyi*, *P. serotina*, *Pyrus baccata*, *Spiraea billiardii*, and *Lonicera ledebourii* (Schlatzer 1964). In dune depressions and sand flats it grows with *Carex pensylvanica* var. *digyna*, *Symphoricarpos occidentalis*, *Rosa woodsii*, and *Agropyron* spp. (Hulett et al. 1966). In the Northern Great Plains, chokecherry grows in shelter belts in combination with *Ulmus pumila*, *Fraxinus pennsylvanica*, *Acer negundo*, and *Prunus americana* (George 1936). On moist sites it is found with *Crataegus douglasii*, *Amelanchier florida*, *Rosa* spp., and *Symphoricarpos* spp. (Shelford 1963).

LIFE HISTORY

The white, densely elongated clusters of strongly-scented flowers bloom from April to July. In northern areas the flowers open later. The thick-skinned, edible fruit is about 5/16 inch in diameter. It ripens from July to September but remains astringent until ripe. Typically, the lustrous clusters of red or amber fruit turn dark red to purplish black at maturity. However, some varieties of chokecherry have different fruit colors. For example, in *P. virginiana* var. *leucocarpa*, the fruit is canary yellow when mature. Fruiting is abundant in most years, but production per plant is unknown. No information was found regarding seed-bearing age of trees.

Birds and mammals are the chief means of seed dispersal. Pits are dropped by birds throughout the fruit-bearing season and later. Primary reproduction of chokecherry is through seed. Once established it grows rapidly and often forms dense thickets of suckers and sprouts from an extensive lateral root system. (Brown 1922, Otis 1960, Van Dersal 1938, Vines 1960).

In most of its range chokecherry is a tall shrub. Only under the most favorable climatic and soil conditions does it become a small tree, 20 to 30 feet high, and it rarely exceeds 8 inches dbh.

Chokecherry is a very competitive shrub, due to its tolerance of adverse climatic and site conditions such as cold temperatures, shade and drought, and its ability to sprout prolifically. The adaptability of chokecherry is indicated by its exceptionally wide geographic distribution. However, chokecherry is subject to many disease and insect attacks, notably black knot disease (Hepting 1971, Hosley 1938) and defoliation by tent caterpillars.

Chokecherry is a host of the apricot ring pox virus, twisted leaf in sweet cherry (Lott and Keane 1960), and the notorious X-disease virus that infects peach and cherry trees (Gilmmer et al. 1954, Wolfe 1955). Infected trees can be symptomless. X-disease spreads rapidly and can ruin an orchard in 3 or 4 years. This disease has caused considerable damage to peach orchards in New York since 1938 (Palmeter and Hildebrand 1943). It has been reported in the Maritime Provinces (Callahan

1964), Wisconsin, Michigan, Pennsylvania, and Connecticut. In areas where chokecherry is rare, as along Lake Ontario, X-disease is unknown (Parker and Palmeter 1951).

USES

Good crops of fruit are born in most years (Vines 1960), and about 70 species of game or song birds seek out fruits as soon as they become available (Bump et al 1947, Longenecker and Ellarson 1960, Van Dersal 1938). Chokecherries are readily eaten by ruffed grouse through the fall till December, but may be less important locally than pin or black cherries (Edminster 1947). The fruits are also eaten by small mammals (Grimm 1951), and the buds and twigs are browsed by ruffed grouse during winter (Phillips 1967). Rabbits have little taste for the bitter twigs of chokecherry (Harlow 1957), but repellents may not keep them from eating the bark (Detroux and Fouarge 1952, Vines 1960). Chokecherry stems ranked fairly high in winter feeding of cottontails in Connecticut (Dalke and Sime 1941).

In northern forests during winter, white-tailed deer and snowshoe hares eat chokecherry, but utilization differs with locality. In southern forests use of cherry species is low (Taylor 1961). Moose on winter range in Wyoming showed a high preference for chokecherry (Harry 1957), and black-tailed deer in Utah used it as a summer staple (Smith 1952).

Chokecherry has fair cover value for small mammals and nesting birds, particularly where it forms thickets (Longenecker and Ellarson 1960) but is of questionable value for landscaping, because of insect and disease susceptibility. Erosion control and shelterbelts are other important uses. And in some instances the fruit is eaten by humans; it makes a jelly with an almond-like flavor (Hosley 1938).

PROPAGATION

Because of the genetic variability of chokecherry and its wide geographic range, seed should be collected or purchased near the area of planting to insure local adaptability and

prevent introduction of strains that may be undesirable.

Seed can be gathered in August to September, either from the ground or by flailing fruit from the trees onto ground cloths. Cleaned seed is sometimes available commercially, and samples have proved 97 percent pure and 94 percent sound (*U. S. Forest Service 1948*). Reported numbers of cleaned seed per pound averaged 5,800, ranging from 3,000 to 8,400 (*Engstrom and Stoeckeler 1941, U. S. Forest Service 1948, Van Dersal 1938, Vines 1960*). Yields of clean seed per 100 pounds of fruit averaged 16 pounds, ranging from 7 to 24 pounds (*Swingle 1939*).

Optimum seed storage conditions are unknown, but good results were obtained from sealed dry storage at 26°F (*U. S. Forest Service 1948*), and seeds of pin cherry have kept for as long as 10 years when stored in sealed containers at 34 to 38°F. Temperatures warmer than about 40°F would probably reduce viability.

Sowing in either September or spring has been recommended. If seeds are to be sown shortly after collection, depulping is not essential, but seed cleaning and a water soak before planting may be beneficial (*Heit 1968*). Cleaned seed to be used in spring planting should be stratified in moist sand or peat for 120 to 160 days at 41°F (*Krefting and Roe 1949*) or for 60 to 90 days at 50°F (*Barton 1939*) before sowing. Seed may germinate in stratification if held too long. Stratified seed should be sown in the spring in drills at 25 seeds per linear foot, covered with $\frac{1}{2}$ inch of

mulch until germination begins, and protected from birds and rodents (*U. S. Forest Service 1948*). The germination rates in one study were between 30 and 70 percent, with a 4:1 ratio between viable seed sown and usable seedlings produced (*Engstrom and Stoeckeler 1941*).

In the nursery, chokecherry is sometimes attacked by the fungus *Coccomyces lutescens* and the bacteria *Bacterium prunii*. Spraying with 4-6-50 or 3-4-50 bordeaux mixture or a 2-percent solution of lime sulfur will control the fungus (*U. S. Forest Service 1948*).

Field planting of various species of cherries is usually done with 1-0 stock on deep well-drained soil in sunny locations free of frost pockets (*U. S. Forest Service 1948*). Specific suggestions on field planting of chokecherry were not found, but this species grows better in partial shade than most other cherries.

MANAGEMENT

Chokecherry is a useful species for wildlife food and cover, erosion control, shelterbelts, and ornamentals. However, the usefulness of the species is impaired by its disease-hosting qualities and livestock-poisoning risk. The leaves are poisonous when wilted (*Harlow 1957*), and chokecherry should not be planted or maintained in pasturage (*Van Dersal 1938*). Its use as an ornamental may also be limited where risk of tent caterpillar infestation is high, but has been recommended for dry, shady locations (*Curtis and Wyman 1933, Kammerer 1934*).

PIN CHERRY

PIN CHERRY, *Prunus pensylvanica* L.f. Also called Bird Cherry, Cerises d'Ete, Fire Cherry, Northern Pin Cherry, Petit Merisier, Pigeon Cherry, and Wild Red Cherry.

By John R. Fulton

Northeastern Forest Experiment Station
Morgantown, West Virginia

RANGE

Pin cherry occurs from Newfoundland and southern Labrador to northern Ontario and west across Canada to British Columbia and south to the Rocky Mountains in Minnesota, Iowa, northern Illinois, northern Indiana, Pennsylvania, and New York and in mountains southward to Virginia, North Carolina, northern Georgia, and eastern Tennessee (Little 1953).

HABITAT

Pin cherry is a northern species; south of Pennsylvania it occurs only in the mountains. Throughout its range, the number of days of snow cover varies from 1 to 10 in the south to 120 days or more in the north, and the average growing seasons are 100 to 210 days (Van Dersal 1938). Average annual precipitation varies from 30 inches in Canada to 80 inches in the Great Smokey Mountains (U. S. Department of Agriculture 1941).

Pin cherry grows on many kinds of soil, from infertile sand to rich loam (Hosley 1938, Keeler 1915). Optimum soil pH is about 5.0 to 6.0 (Spurway 1941). In the north, pin cherry is found in nearly all forest types, usually in clearings, where it often forms thickets. In the

south it grows at elevations of about 2,500 to 4,500 feet (Core 1929, Stupka 1964). Pin cherry attains its largest size on western slopes of the Great Smokey Mountains in eastern Tennessee (Sargent 1949).

A shade-intolerant pioneer species, pin cherry often invades roadsides, old fields, burns, and similar openings. It often dominates these sites either in pure stands or with species such as aspen, red maple, black cherry, and white or gray birch (Society of American Foresters 1967). It is characteristic as a short-lived tree in hemlock, northern hardwoods, and spruce-fir forests (Core 1929, Shanks 1954). Pin cherry is a dominant natural revegetation species of coal-spoil banks in Pennsylvania (Bramble and Ashley 1955).

LIFE HISTORY

Pin cherry flowers from April to early June, when the leaves are half grown. The flower is perfect, white, $\frac{1}{2}$ inch across, and is born on a slender stalk in a four- or five-flowered group which usually is clustered with two or three other groups. The fruit is a red drupe, $\frac{1}{4}$ inch in diameter, and is thin-skinned and sour. Fruits ripen from July to August and may persist on the trees until October or later

(Keeler 1915, U. S. Forest Service 1948). Seed dispersal by birds and gravity occurs from July into the winter months (Keeler 1915, U. S. Forest Service 1948).

In a 4-year study in West Virginia involving pin cherries with an average dbh of 4.7 inches, the average fruit yield was 0.68 quarts per tree, half the trees bore fruit, and fruit yields varied substantially among years. The average fruit-ripening date was 31 August, and the latest date of fruit persistence was 6 October (Park 1942).

Pin cherry usually occurs as a tree 31 to 40 feet tall at maturity, but in the southern Appalachians specimens up to 91 feet tall and 5 feet 4 inches in circumference have been found (Stupka 1964). Pin cherry aggressively invades cleared areas and grows fast, particularly when young (Keeler 1915). Once established, it will reproduce by suckering and sometimes forms thickets on poor soils (Wright 1915). However, it is susceptible to several fungous diseases and parasitic insects, and has a shallow root system. Pin cherry seldom lives over 30 years and is usually replaced by shade-tolerant trees (Hosley 1938).

USE BY WILDLIFE

Pin cherry is an important wildlife food source. The fruit is eaten in summer and fall by at least 25 species of non-game birds, several upland game birds, fur and game mammals, and small mammals (Martin et al 1951). Pin cherry fruit constituted 4.5 percent of the fall diet of ruffed grouse in the Northeast (Edminster 1947). The buds are used by upland game birds, especially sharptailed and ruffed grouse. Foliage and twigs are browsed by deer (Martin et al 1951); however, a study showed the foliage to have an undesirably high calcium to phosphorus ratio for good deer nutrition (Bailey 1967). Pin cherry is also browsed by the cottontail rabbit (Sweetman 1944).

Pin cherry provides only fair nesting cover and materials for birds (Longenecker and El-larson 1960), but this value would presumably be greater where pin cherries form dense thickets.

Beaver will cut pin cherry, sometimes completely removing small stands at the detriment of other wildlife.

PROPAGATION

The ripened fruits can be collected in late summer from trees or the ground. They should then be cleaned of pulp and can be sown early in the same fall, by planting 1 inch deep in mulched beds. Soaking the seeds in water before planting may be of benefit, but scarification is not necessary (Heit 1967c). If seeds are to be held over winter, they should be stratified in moist sand for 60 days at 68 to 86°F, then for 90 days at 41°F (U. S. Forest Service 1948). Seeds of pin cherry have retained viability for as long as 10 years when stored in sealed containers at 34 to 58°F (Heit 1967e).

The yield of cleaned seed was reported as 16 pounds per 100 pounds of fruit, and the number of cleaned seed per pound averaged 15,700 (U. S. Forest Service 1948). Seed may be available commercially from at least one source, but planting stock apparently is not sold (NE Regional Technical Center 1971).

Pin cherry is used as grafting stock because the wood unites readily with that of sour cherry (*P. cerasus*) (Wright 1915). Stocks are worked more commonly by budding than by grafting (Bailey 1950).

Little is known about field propagation of pin cherry, but recommendations for nursery practices may suggest field techniques. Once established, pin cherry usually maintains itself until it is overtaken by competing trees. It suckers readily and should grow well from root cuttings (Bailey 1950).

MANAGEMENT

Pin Cherry is a convenient species for use by wildlife managers who desire a fast-growing, aggressive, small tree that is widely utilized by game and other animals. It will provide quick cover on denuded land because it tolerates extreme soil conditions. Seeds of pin cherry have very hard coats and accumulate in the humus layer of the forest floor. They will germinate profusely when influenced by fire or lumbering operations (Hosley 1938).

Pin cherry will produce well under moderate to heavy deer browsing, and should be browsed at least moderately to keep plant growth within reach of deer (Aldous 1952).

But, most commonly, the wildlife values of pin cherry are obtained incidentally to its occurrence rather than through purposeful management. Despite its desirable qualities of wildlife use, soil-binding capability, and stock for commercial cherries, pin cherry is not widely cultivated.

Pin cherry is plagued by several diseases and parasites, which may spoil its appearance, at least. The most prominent leaf disease is cherry leaf spot, caused by the fungus *Cocco-
myces hiemalis*. This disease results in characteristic holes in the leaves and premature leaf fall. Repeated attacks reduce vigor of the tree. Another common disease is black knot, caused

by the fungus *Dibotryon morbosum*. This can be recognized by the numerous large black galls on the branches and twigs (*Hepting 1971*). The eastern tent caterpillar (*Malocasoma disstria*) sometimes completely defoliates cherries. Although pin cherries withstand repeated attacks of these insects, dead limbs, defects, and growth loss may occur (*Kulman 1965*).

Pin cherry has been controlled by spraying mixtures of 2,4-D and kerosene on foliage, stems, or stumps (*Day 1948*). Equal mixtures of 2,4-D and 2,4,5-T also have proved effective in killing seedlings and suckers (*Egler 1949*).

SWEET CRAB APPLE

Malus coronaria (L.) Mill.
(Pyrus coronaria L.)[†]

Also called American Crabapple, Crabapple, Fragrant Crab, Garland-Tree, Narrow-Leaf Crab-Apple, Scented Crab, Wild Crab, Wild Crab Apple, and Wild Sweet Crab Apple.

By Robert W. Donohoe

*Ohio Department of Natural Resources
New Marshfield*

RANGE

Sweet crab apple does not occur naturally in the New England States or the Maritime Provinces. Range of the typical form is from central New York and southern Ontario to southern Wisconsin, south to Delaware, and in uplands to South Carolina, Tennessee, and Missouri. The variety *dasycaalyx* is common in the western part of this area, particularly in Ohio and Indiana, and ranges to Minnesota and Kansas. Along the southern Appalachians, sweet crab apple occurs up to altitudes of 3,300 feet (Fernald 1950, Little 1953, Sargent 1922).

HABITAT

The range limits of sweet crab apple indicate that it is not adapted to the colder climates, northward or at high elevations, within the Northeast. Within its range limits, crab apple occupies a wide variety of soils and topographical situations (Charles M. Nixon, personal communication concerning Ohio; Van Dersal 1938). The tree does best in full sunlight on moist but well-drained, fairly heavy

soils (Hough 1907, Van Dersal 1938). The soil pH preferences are not documented, but may approximate those for prairie crab apple (*M. ioensis*): 6.0 to 6.5 for nursery soils and 5.5 to 8.0 for field soils (Wilde 1946). Although sweet crab apple does best on moist, rich soils, it will tolerate drier soils of moderate fertility (Edminster 1947, Van Dersal 1938).

Sweet crab apple is often found in forest glades among taller trees (Hough 1907). In Ohio it is associated with old-field succession and commonly occurs with hawthorn, elm, ash, hickory, and sumac (Charles M. Nixon, personal communication). In southeastern Ohio, sweet crab apple on slopes of northern exposure is associated with pawpaw, flowering dogwood, hawthorn, American hophornbeam, sourwood, pin cherry, and sassafras; on ridges with serviceberry, pawpaw, flowering dogwood, common apple, and sassafras; and on flood plains with pawpaw, spicebush, wahoo, wild plum, and elderberry (Hart 1951).

A survey of spoil resulting from strip-mining for limestone in northeastern Ohio (Stark County) revealed good natural plant invasion and establishment after 21 years. Sweet crab

apple had become established along with white ash, black cherry, American elm, red elm, cottonwood, sassafras, hawthorn, and red-osier dogwood (Riley 1952).

LIFE HISTORY

The flowers of sweet crab apple appear in March to May and are white and flushed pink. The fruits ripen in late summer or early fall, are yellow-green in color, and are 1 to $1\frac{1}{4}$ inches in diameter (U. S. Forest Service 1948, Van Dersal 1938). Leaf color in the fall is yellow, and nearly all leaves are off by November 1.

In Michigan an 8-year study of fruit production by 13 species of plants that may be used by wildlife showed that crab apple had the largest mean weight (103 g, range 1.2 to 162.9 g) per square foot of crown surface (Gysel and Lemmien 1964). In another Michigan study, sweet crab apple was considered to be a heavy and consistent fruit producer. The fruits ripened by October; nearly all had fallen by December 1, but some persisted until January 1. Fruits softened after falling and were badly discolored by December 1 (Hosley 1938). A fruit-production survey on sweet crab apple in southern Ohio (Scioto County) for three successive years revealed that out of a sample of 100+ trees, 40 percent produced fruit in 1935, 10 percent produced fruit in 1936, and 50 percent produced fruit in 1937 (Chapman 1938).

The fruit of sweet crab apple contains 4 to 10 small- to medium-size dark seeds. Heavy seed crops are produced every 2 to 4 years, and medium to light crops in intervening years. One pound of cleaned seed can be obtained from 100 pounds of fruit (Swingle 1939). The average number of cleaned seed per pound was reported as 14,000, but may be as much as 70,000 (Edminster 1947, Isely 1965). In nature, the seed is disseminated by gravity and animals (U. S. Forest Service 1948).

Sweet crab apple reproduces primarily from seed. The tree attains the height of 25 to 30 feet, has a trunk rarely more than 12 to 14 inches in diameter, and when isolated develops a broad top, 20 to 25 feet in diameter, with rigid branches bearing many short branchlets

terminating in sharp spur-like leafless tips (Hough 1907).

The sweet crab apple is not shade-tolerant. It is part of the old-field succession and often forms dense spiny thickets when it does not have competition from overstory trees. It is sometimes found growing in the forest understory; however, in this situation, growth is poor and fruit production is minimal.

USE BY WILDLIFE

The apples include about 25 species, many of which are of value to wildlife, and one of the chief uses of sweet crab apple is for wildlife food (U. S. Forest Service 1948).

Data about use of sweet crab apple are scanty. But the following information about all apple species collectively seems to apply reasonably well to sweet crab apple. Ruffed grouse, ring-necked pheasant, and bobwhite quail eat the fruit, seeds, and buds of apple. The purple finch, grackle, blue jay, baltimore oriole, orchard oriole, robin, yellow-bellied sapsucker, starling, tufted titmouse, rufous-sided towhee, cedar waxwing, and the downy, hairy, red-bellied, and red-headed woodpeckers eat the fruits and seeds. The fruit and bark of the apple are eaten by the black bear, gray and red fox, opossum, porcupine, cottontail rabbit, raccoon, eastern skunk, fox squirrel, deer and pine mouse, and Allegheny wood rat. The twigs and foliage are browsed by white-tailed deer (Martin et al 1951).

A food-habit study of white-tailed deer in Ohio showed that fruit of the sweet crab apple ranked first in the diet of animals from the eastern part of the state (Nixon and McClain 1966).

Sweet crab apple provides excellent cover for many wildlife species, especially where it forms dense spiny thickets in old fields.

PROPAGATION

Ripe crab apples can be picked from the trees or gathered from the ground in September or later. A bushel of fruit yields 2 to 3 pounds of cleaned seed; and, as a rule of thumb, a pound of cleaned seed may produce about 2,000 usable seedlings (Edminster 1947).

Seeds can be extracted by macerating the fruit in water and floating off or screening the pulp. The wet seed mass can be fermented, in a waterbath with yeast added, but must not remain in the bath longer than 48 hours (*Edminster 1947*). Cleaned seed should then be dried, and, if necessary, can be stored in sealed containers, at temperatures just above freezing. Apple seeds (*M. pumila*) stored in this way retained viability for at least 2½ years (*U. S. Forest Service 1948*).

Seeds can be stratified in moist sand or peat at 41°F for 60 to 120 days. The longest period, 120 days, hastened subsequent germination (within 24 days), whereas the germination time was longer (within 104 days) following 60-day stratification. In other words, total time to germination was about 21 weeks with 120-day stratification and over 23 weeks with 60-day stratification (*U. S. Forest Service 1948*).

Fresh seeds can be sown in the fall, at the rate of 1 pound of seed per 100 square feet of soil, and then covered with ¼ inch of soil plus mulch (*Edminster 1948*). Seeds of a closely related species (*M. ioensis*), collected when slightly green and sown immediately, germinated 100 percent the following spring. Alternatively, stratified seed can be sown in the spring, preferably in drills (*U. S. Forest Service 1948*).

Optimum planting density in the nursery is about 10 plants per square foot. Seedlings are ready for outplanting when about 6 inches tall by 3/16 inch diameter above the root collar, as 1-0 or 2-0 stock (*Edminster 1947*).

Sweet crab apples can be outplanted in a variety of soils and site conditions. They do best when grown in a moderate temperate climate on a clay-loam soil (*U. S. Forest Service 1948*). Fallow fields, fields in the early successional stages, and forest openings are places where sweet crab apple can be established.

Flowering crab apple (*Malus sp.*), at least, can also be propagated by whip grafting onto apple seedling roots in January or February. The stocks are dug in the fall and stored until used. Six- or 8-inch scions should be used on about 3-inch root pieces. The unions are tied with waxed string, and the grafts are stored overwinter like hardwood cuttings, or set singly in boxes of moist peat and lined out in a similar way in the spring. If set deep in the soil, many of them develop their own roots (*Laurie and Chadwick 1931*).

MANAGEMENT

Sweet crab apple in old fields can be managed by preventing the invasion of overstory species. Cutting, girdling, or using herbicides on invading trees, which would eventually cause shade, may be the best management technique.

Sweet crab apple may be controlled in part by using herbicides equivalent to 2,4-D, or 2,4-D and 2,4,5-T (equal parts of each). When used at the rate of 3,000 parts per million, diluted in water and applied to foliage, these herbicides gave good control on young seedlings, but only fair control on older trees (*Rudolf and Watt 1956*).

MISCELLANY

The wood of sweet crab apple is heavy, close-grained, not strong, light red, with yellow sapwood of 18 to 20 layers of annual growth. It is used for levers, tool handles, and many small domestic articles. The tree is sometimes planted in gardens in northern and eastern states (*Sargent 1922*).

The fruit of sweet crab apple makes a delicious marmalade or jelly (*Fernald and Kinsey 1943*), or cider and vinegar (*Isely 1965*).

Crab apples are susceptible to air-pollution damage from HCl, Cl₂ and ozone (*Sucoff and Bailey 1971*).

DOGWOODS

FLOWERING DOGWOOD, *Cornus florida* L. Also called Arrowwood, Boxwood, Cornelius-Tree, Dogwood, False Box, Florida Dogwood, Nature's Mistake, White Cornel.

ALTERNATE-LEAF DOGWOOD, *Cornus alternifolia* L.F. Also called Blue Dogwood, Gray Dogwood, Green Osier, Osier, Pagoda Dogwood, Red Osier.

ROUNDLEAF DOGWOOD, *Cornus rugosa* Lam. Also called Bois de Calumet.

SILKY DOGWOOD, *Cornus amomum* Mill. Also called Kinnikinnik, Red Willow, Silky Cornel, Squawbush.

By Walter A. Lesser

*Department of Natural Resources
Elkins, West Virginia*

Jean D. Wistendahl

*Ohio University
Athens*

RANGE

The four species of dogwood discussed here are found in most of the Northeast, but two are rare or absent in Canada.

Flowering dogwood ranges north from Florida and Texas to southwestern Maine and southern New Hampshire and Vermont, west to southern Ontario and Michigan and south to Missouri and Kansas (*Little 1953*).

Alternate-leaf dogwood ranges farther north, into New Brunswick and Nova Scotia and westward along the St. Lawrence valley to the northern shores of Lake Superior and to eastern Minnesota. The southern limits are eastern Kentucky, Ohio, West Virginia, Maryland, Delaware, and New Jersey (*Sargent 1922*).

Silky dogwood ranges from southern Maine to southern Illinois and Indiana south to South Carolina and Alabama (*Gleason and*

Cronquist 1963). Roundleaf dogwood, a more northern species, is found from Quebec to northern Ontario, south to New Jersey, Pennsylvania, northern Ohio to northeastern Iowa, and in the mountains to Virginia (*Gleason and Cronquist 1963*).

HABITAT

These dogwoods are found either as under-story species in many forest types or as thicket-forming shrubs of fields and wet areas. Within the ranges of these four dogwoods, annual precipitation varies from a low of 30 inches per year in the north to a high of 80 inches in Florida, where there is no snowfall, to more than 50 inches of snow in the north. Temperature extremes are from -30° to 115°F (*Fowells 1965*). The growing season ranges from 160 days in southern Michigan to 300 or more days in Florida (*Fowells 1965*).

Dogwoods tolerate a wide variety of climatic conditions, but roundleaf dogwood does not range beyond the southern reaches of the Northeast except in the mountains to Virginia (Gleason and Cronquist 1963).

Flowering dogwood is one of the most adaptable and widely distributed understory trees of the eastern deciduous forests—growing in a variety of soils from well-drained uplands to the deep, moist soils of streambanks (Fowells 1965). It is commonly found on soils having pH values of 5 to 7 (Spurway 1941); and optimum growth occurs in moist fertile loam that is slightly acid (Fowells 1965). In cut-over loblolly pine stands on the Virginia coastal plain, flowering dogwood was most common on soils having good drainage and light texture; it was almost absent on poorly-drained, heavy soils (Wenger 1956).

Alternate-leaf dogwood grows in rich woodlands, along the margins of forests and along streams in moist well-drained soils (Ammons 1950, Sargent 1922) as well as in dry woods and on rocky slopes (Fernald 1950). Silky dogwoods occurs in more moist situations, especially along streams (Ammons 1950, Gleason and Cronquist 1963) and in swamps and thickets (Fernald 1950). Roundleaf dogwood occurs mostly in dry woodlands and on rocky slopes (Fernald 1950).

Although flowering dogwood is most prominent in two forest types, scarlet oak and white oak-red oak-hickory, it is found in many hard wood and conifer types (Fowells 1965). In the scarlet oak type, dogwood associates are: scarlet, southern red, chestnut, white, and post oaks; hickories; blackgum; sweet gum; black locust; and pitch, shortleaf, and Virginia pines. In the white oak-red oak-hickory type, flowering dogwood is associated with yellow-poplar; pignut, shagbark, and mockernut hickories; white ash; red maple; beech; and blackgum (Fowells 1965).

The following species are associated with flowering dogwood in the moist, climax forest understory: magnolias (*Magnolia tripetala*, *M. macrophylla*, and *M. fraseri*), sourwood, striped maple, redbud, American hornbeam, eastern hophornbeam, American holly, and downy serviceberry (Braun 1950). In the hill section of Indiana, flowering dogwood is con-

spicuous in the understory. It is a dominant understory species in the white oak forests of the Shenandoah Valley (Braun 1950).

Alternate-leaf dogwood is among the shrubs that are generally abundant in moist woods, along with spicebush, witch-hazel, pawpaw, and wild hydrangea (*Hydrangea arborescens*) (Braun 1950). In oak forests at moderate elevations, the understory may include alternate-leaf dogwood, witch-hazel, mountain-camellia (*Stewartia ovata*), mountain winterberry, and Virginia creeper. Rhododendron and mountain-laurel may be present, particularly if eastern hemlock is in the canopy (Braun 1950). In the sugar maple-white elm areas in Alger County, Michigan, alternate-leaf dogwood, prickly gooseberry (*Ribes cynosbati*), and virgin's-bower (*Clematis virginiana*) are widely distributed along with more northern species such as American yew, mountain maple, red-berried elder, beaked hazel, and American fly honeysuckle (Braun 1950). In Colebrook, Connecticut, alternate-leaf dogwood along with witch-hazel, mapleleaf viburnum, and American fly honeysuckle are frequently found in mature forests (Braun 1950).

In the sugar maple-basswood forests of the Midwest, roundleaf dogwood and bush-honeysuckle (*Diervilla lonicera*) are the northern species of shrubs indicative of the transitional nature of this zone (Braun 1950). In the mixed forest of the hemlock-white pine-northern hardwoods region, there are a large number of shrubs and small trees including roundleaf dogwood, alternate-leaf dogwood, mountain maple, serviceberry, eastern hophornbeam, American mountain-ash, gooseberries (*Ribes spp*), beaked hazel, rope-bark (*Dirca palustris*), bush-honeysuckle, American fly honeysuckle, and thimbleberry (*Rubus parviflorus*) (Braun 1950).

In a study of old fields on the floodplain of the Raritan River in New Jersey, silky dogwood was found in association with blackberries, poison ivy, shining sumac, smooth sumac, blackhaw viburnum, southern arrow-wood, Carolina rose, bayberry (*Myrica pensylvanica*), gray dogwood, and grape (Wistendahl 1958).

LIFE HISTORY

The flowers of flowering dogwood are greenish white to creamy, perfect, in heads surrounded by four showy, petal-like, white, deciduous bracts (pink in the form *rubra*) (Preston 1966). The flowers open at the same time the leaves expand—in March at the southern end of the range to June in northern areas (U. S. Forest Service 1948). The light cream-colored flowers of alternate-leaf dogwood are in broad flat open clusters that open from May in the south to June in the north (Ammons 1950). Flowers of the two other species are white, in flat clusters, and appear from May to July (Ammons 1950).

Fruiting time varies with species and location. Flowering dogwood has ovoid scarlet fruits $\frac{1}{2}$ inch long and $\frac{1}{4}$ inch wide with thin, mealy flesh (Fowells 1965). The fruits ripen from September to late October (U. S. Forest Service 1948). Alternate-leaf dogwood has a dark blue, globe-shaped fruit about $\frac{1}{3}$ inch in diameter when it ripens in September (Ammons 1950). The fruit clusters are loose, spreading, and red-stemmed (Brush 1957). The pale blue fruits of silky dogwood are also in loose clusters and ripen in September (Ammons 1950). Fruits of roundleaf dogwood are light blue and sphere-shaped; they ripen from August to October (Ammons 1950, Fernald 1950).

Flowering dogwood bears good seed crops about every other year, but seeds from isolated trees are frequently hollow (U. S. Forest Service 1948). Both wild and nursery-grown flowering dogwoods fruited for the first time at 6 years of age (Spinner and Ostrom 1945). Seed is dispersed in October to late November or later, by gravity, birds, and other animals (U. S. Forest Service 1948). The number of seeds per ounce averaged 280, with a range from 200 to 390 (U. S. Department of Agriculture 1961a). The yield of seed per 100 pounds of fruit ranged from 22 to 46 pounds, and the average number of cleaned seed per pound was 4,500 (U. S. Forest Service 1948).

In a yield and fruit-persistence study of flowering dogwood in West Virginia for a 4-year period, 71 percent of the plants produced fruit, average date of ripening was September 20, and the latest date of fruit persistence on

the plants was December 2. The plants exhibited a crop failure in 1 of the 4 years (Park 1942). In Texas, 88 percent or more of trees 3½ inches dbh and larger fruited each year. Year-to-year differences were more pronounced in the smaller diameter classes. The fruit ripened in September and some persisted on trees until January. Average fruit production was 37.9 pounds per square foot of basal area (Lay 1961). Flowering dogwood yields fruit under a heavy overhead canopy even in a poor seed year if the site is fair to good (Crawford 1967).

Alternate-leaf dogwood yields of cleaned seed ranged from 5,900 to 9,500 and averaged 8,000 seeds per pound (U. S. Forest Service 1948, Vines 1960). Seed is dispersed from July through September (U. S. Forest Service 1948).

Silky dogwood seeds are dispersed from September to mid-October. Seed yields were 17 pounds of cleaned seed per 100 pounds of fruit and 10,900 to 11,600 cleaned seeds per pound (U. S. Forest Service 1948). In southwest Michigan, fruits remained on the shrubs for about 90 days after ripening (Gysel and Lemmien 1955). The average germination of silky dogwood was reported to be 10 percent (Forbes 1955). Annual fruit production for an 8-year period on the Kellogg Forest in Michigan ranged from 0.7 g per square foot of crown surface to 46.6 g and averaged 17.9 g (Gysel and Lemmien 1964).

No information was found on seed production of roundleaf dogwood. This species occurs only infrequently throughout its range (Ammons 1950).

Natural germination of dogwood seed occurs in the spring after the seed has fallen and lain on the ground over winter. All species of dogwood show delayed germination due to embryo dormancy and, in some species, to impermeability or hardness of the seed coat (U. S. Forest Service 1948). The best natural seedbeds are moist, well-drained, rich loams (Vimmerstedt 1957).

Flowering dogwood seedlings usually show rapid root growth. Height growth is relatively fast during the first 20 to 30 years but then practically ceases, although individual plants may live 125 years (Fowells 1965). Flowering

dogwood has a long growing season. In a Massachusetts nursery, flowering dogwood displayed a height growth pattern different from that of any other species studied. The dogwoods grew from 24 April to 4 September, and 90 percent of growth occurred during 95 days from 15 May to 18 August. The most rapid growth occurred during the first week in August, then growth suddenly slowed down.

This species has been reported to grow nearly all summer, but to stop temporarily during periods of adverse conditions (Kozlowski and Ward 1957). In the Georgia Piedmont, the most rapid radial growth of stems occurred during an 80- to 89-day period. Half of the total radial growth was completed in 40 to 49 days (Jackson 1952).

Soil moisture was the most important factor determining survival of 1-year-old flowering dogwood seedlings in the North Carolina Piedmont (Ferrell 1953). In another North Carolina Piedmont study, flowering dogwood seeds were planted in three situations: in an open field, under pine stands, and on the margins of pine stands. Survival was significantly higher on the margins of pine stands than on the other two sites, but there was no significant difference in survival between the open field and the pine forest. The intermediate light intensity of the margins provided some advantage that compensated for a reduced water supply. However, dogwood growth was greater in the open than in the margin or the pine forest. Seedlings in the forest were the smallest (Kramer et al 1952).

Flowering dogwood reproduces by sprouting, and it sprouts most profusely when cut in late winter (Buell 1940). It also reproduces extensively by layering (Spector 1956, U. S. Forest Service 1948, Vines 1960).

Maximum height for flowering dogwood on good sites is about 40 feet, with a dbh of 12 to 18 inches, attained in 20 to 30 years (Fowells 1965). Near the northern limits of its range, flowering dogwood becomes a many-branched shrub (Vimmerstedt 1957). Alternate-leaf dogwood, under favorable conditions, becomes a small tree not more than 30 feet in height, with a short trunk 6 to 8 inches in diameter (Sargent 1922). Silky dogwood, with its upright to spreading form, grows to a height of 3

to 10 feet (Vines 1960). Roundleaf dogwood is a shrub reaching 6 to 10 feet (Ammons 1950).

Flowering dogwood is well adapted as an understory tree. It has the ability to carry on maximum photosynthesis at one-third of full sunlight, which helps explain how it survives and grows under a forest canopy (Fowells 1965). Flowering dogwood is comparable in shade tolerance to white oak (Vimmerstedt 1957).

Because flowering dogwood has thin bark, it is readily injured by fire. In the Northeast, fires killed the above-ground parts of all the flowering dogwoods on a study area after 1 year (Stickel 1935). Fire-damaged trees, however, have ability to sprout profusely (Vimmerstedt 1957). Once trees reach 10 to 15 feet in height they can withstand infrequent winter burns of low intensity (Halls and Oefinger 1969).

Flooding is also detrimental to flowering dogwood. In one experiment, flooding killed all potted seedlings in 1 to 3 weeks (Parker 1950). Flowering dogwood is also susceptible to drought, although it can tolerate low and high temperatures. In prolonged periods of drought, the leaves often turn red and curl, and severe dieback of the top may result (Vimmerstedt 1957).

USE BY WILDLIFE

The dogwoods are extremely valuable for wildlife. The seed, fruit, buds, flowers, twigs, bark, and leaves are utilized as food by various animals.

As a wildlife food, the most distinguishing quality of flowering dogwood is its high calcium content. Samples collected in southern pine-hardwood forests contained 1.72 percent calcium in leaves, 1.44 percent in twigs, and 0.89 percent in fruits. These amounts are well above those needed by wildlife for good skeletal growth (Halls and Oefinger 1969). Compared with other fruits, flowering dogwood is outstanding for its content of calcium and fat. Fruit collected in Texas had the following percentage composition: protein 5.49, fat 16.17, fiber 24.64, ash 4.96, phosphorus 0.6, and calcium 1.10. Leaves and twigs contained 1.75 to 2.90 percent calcium (Lay 1961).

Alternate-leaf dogwood was deficient in

phosphorus, as were 11 of the 20 plant species analyzed in a study of the mineral content of deer browse on the Huntington Wildlife Forest in New York (Bailey 1967).

Flowering dogwood has been recorded as food taken by at least 36 species of birds, including ruffed grouse, bob-white quail, and wild turkey. Records of mammals eating this dogwood include eastern chipmunk, white-footed mouse, gray fox, skunk, cottontail rabbit, white-tailed deer, beaver, and gray squirrel (Chapman 1947a, Van Dersal 1938, Vines 1960). In the Missouri Ozarks, flowering dogwood contributed as much or more than any other soft-fruited species to the diet of wild turkeys, and was prominent in the diet of turkeys from fruit ripening in September until February (Dalke et al 1942). Dogwood fruit was in 10 percent of 115 crops from wild turkeys collected on the George Washington National Forest during three falls and early winters. Dogwood was fourth in importance among all foods (Martin et al 1939). Flowering dogwood ranked 21st on a list of quail food plants of the Southeast, and was listed as a preferred food of the wild turkey (Vines 1960). In east Texas, fruit of flowering dogwood was found in 16 percent of 49 deer stomachs collected in November and December. Fruit remains were also found in deer pellet groups (Lay 1965a). In a study of cottontail rabbits in southwest Michigan, flowering dogwood rated second among 18 winter food plants (Haugen 1942). In Massachusetts, winter food choices among 100 species of woody plants were analyzed for relative attractiveness as food of the cottontail rabbit. Browsing by rabbits severely injured the flowering dogwood but injured alternate-leaf dogwood only slightly (Sweetman 1944).

Fruits of alternate-leaf dogwood have been reported eaten by at least 11 species of birds, including ruffed grouse. Black bears may be especially fond of this fruit (Chapman 1947a). Leaves and stems are eaten by white-tailed deer and cottontail rabbits (Van Dersal 1938, Vines 1960).

Silky dogwood fruit is utilized by at least 10 species of birds (including ruffed grouse, bob-white quail, wild turkey, and ring-necked pheasant), and cottontail rabbit, woodchuck,

raccoon, and squirrels. Cottontails eat the fruit and browse the stems (Holweg 1964, Van Dersal 1938). In West Virginia, wood ducks readily eat silky dogwood fruits in late summer and fall, before and after ripening. Wood ducks have been seen reaching as far as they can from the water to strip the shrubs of fruit.

Roundleaf dogwood fruit has been found in stomachs of ruffed grouse and sharp-tailed grouse, and feeding observations have been made of the blue-headed vireo, cottontail, and moose (Van Dersal 1938). A ruffed grouse from Delaware County, New York, had eaten 226 roundleaf dogwood fruits on December 20 (Bump et al 1947).

All species of dogwoods possess cover value, but that of roundleaf is least due to its infrequent occurrence (Korschgen 1960, McAtee 1936). Animals trapped or observed in plantings of silky dogwood on the Kellogg Forest in Michigan included short-tailed shrew, striped ground squirrel, red squirrel, white-footed mouse, meadow vole, and meadow jumping mouse (Gysel and Lemmien 1955). A study of power line right-of-way vegetation and animal use in southern Michigan revealed that the silky dogwood-willow shrub community was used by cottontails, raccoon, red squirrels, and opossums (Gysel 1962). In West Virginia, silky dogwood on streambanks provides brood and escape cover for wood ducks. The thicket-forming silky dogwood also provides cover for woodcock.

PROPAGATION

Because these dogwoods, except roundleaf, are highly prized for ornamental purposes, seed (dried fruit or cleaned stones) and planting stock are available from commercial growers. Dogwoods can be grown from root cuttings, layering, and by division, as well as from seed (Fowells 1965). If seed is to be collected, isolated plants should be avoided because they often have a high percentage of empty stones, in flowering dogwood at least (U. S. Forest Service 1948).

Because the fruit pulp contains an unknown chemical that delays germination (Goodwin 1948), cleaned seeds are preferable for germination in the nursery. The pulp may be removed by soaking fruit in water for a few days

until the covering is soft and easy to remove (*Free 1957*). Large quantities of fruit may be macerated in water or run through a hammer mill, allowing pulp and empty stones to wash away (*U. S. Forest Service 1948*). Dogwood seed should then be dried and stored in an airtight container at 34 to 38° F.

Stratification is necessary to break seed dormancy. The seed can be stratified in moist sand or peat moss for four months at 33 to 41° F. Seed can be sown in drills or broadcast and covered with $\frac{1}{4}$ to $\frac{1}{2}$ inch of nursery soil depending on the size of the seed. Forty of the smaller seeds are sown per square foot and mulched with leaves or straw. The mulch is removed as soon as germination begins (*U. S. Forest Service 1948*).

In nurseries where small lots of seeds are used, broadcast sowing is recommended; and for fall sowings, heavy mulch is needed for winter protection. A heavy mulch prevents solid freezing of seeds during an open winter and may induce much higher germination the following spring (*Heit 1968*). For seeding in the fall, seeds should be gathered just as they go into the meaty stage, but before the outside coat becomes hardened or impervious to moisture and air.

In one test, seeds of alternate-leaf dogwood gathered and planted on 8 July attained a germination of 100 percent the following spring. Roundleaf dogwood seed gathered and planted on 2 September also had a germination of 100 percent the following spring (*Titus 1940*). But seeds of alternate-leaf and roundleaf dogwoods usually are extremely dormant and probably should be sown in July or early August or stored, stratified, and seeded in the spring as previously described. Silky and flowering dogwood seed are less dormant and may be fall-seeded in September or October (*Heit 1968*). One author reported greater success with spring seeding than fall seeding and used builder's sand as the stratification medium (*Miller 1959*). Nursery germination of flowering dogwood seed may range from about 77 percent to 85 percent (*U. S. Forest Service 1948*).

The number of usable plants (1-0 or 2-0 stock) per pound of clean seed was 200 for flowering dogwood and 1,400 for silky dogwood (*Bump et al 1947*).

Dogwoods are reproduced vegetatively by various means: softwood cuttings in summer, hardwood cuttings in winter, grafting in winter or spring, layering in spring and summer, from suckers and divisions in spring, and budding in the summer (*Mahlstede and Haber 1957*). Vegetative reproduction is necessary to propagate plants for characteristics such as color of flowers and fruit retention.

Flowering dogwood roots readily from cuttings taken in June or immediately after the plants bloom. The advantages of taking cuttings early in the season are that they obtain maximum growth and harden off before the first winter. Only terminal shoot tips should be used, trimmed to 3 inches in length and leaving two to four leaves (*Pease 1953*). One author claimed that rooting was faster when four leaves were retained rather than two (*Doran 1957*). Dogwood cutting results were better when a medium of sand or sandy soil was used rather than peat moss (*Doran 1957, Pease 1953, Vermeulen 1959*). The cutting bases should be dipped in a mixture of indolebutyric acid crystals and talc, one part acid crystals to 250 parts talc by weight. Cuttings are then set 1-1/4 inches deep in the rooting medium. The cuttings should be removed in early August and placed in a cold frame in light, well-drained soil with a pH of about 5.0 (*Pease 1953*). Cuttings from young trees usually show better growth after rooting than do cuttings from mature trees; also the survival of rooted cuttings from old trees may be poor (*Doran 1957, Pease 1953*). In addition to the indolebutyric acid treatment, one author reported that wounding the cuttings provided a better distributed root system (*Bridgers 1955*).

The red form of flowering dogwood (*C. f. rubra*) is difficult to start from cuttings and is usually propagated by budding in late summer or whip-grafting in winter on flowering dogwood seedlings (*Hartmann and Kester 1968*).

Dogwoods can be propagated successfully by grafting during the winter or early spring months. Scions may be collected in advance of the grafting work, and stored for 3 or 4 weeks in plastic containers with a small amount of sphagnum moss to prevent drying. Scions should be restricted to wood of the previous growing season. Wood to be used as scions

should be about the diameter of a lead pencil, 8 to 12 inches long, and should contain three or 4 sets of buds (Coggeshall 1960). Grafting techniques most commonly used include the whip-and-tongue method, side graft, and bench or bare-root graft (Coggeshall 1960, Wells 1955). A disadvantage in the whip-and-tongue method is the total loss of the seedling rootstock in the event of graft failure. This does not occur when a side graft is used (Coggeshall 1960).

Some dogwood graft failures have been attributed to a black mold fungus appearing as a crumbly, crust-like black layer on cut surfaces of both the rootstock and scion. The mold prevents callus formation. Growers have reported losses as high as 60 to 70 percent of their grafts. Control of this fungus is through sanitation and use of healthy vigorous stock (Collins 1960).

Dogwoods are budded in late July or early August, using 1-year-old seedlings in the field. The shield or T-bud method is normally used, placing the bud as low as possible and on the southwest side of the seedling. This results in a straight plant. The following spring, before the bud starts growth, the tops of the seedlings are removed by cutting just above the new bud union (Shadow 1959).

Layering is a satisfactory method of propagating dogwoods. Plants produced by layering soft, growing shoots are often superior to those raised from hardwood cuttings. Layering is done by starting against the base of the stock plant and working out, layering the shortest shoots first. A slight twist is all that is needed, but small pegs should be used to keep the layers firm. The layers are lifted the following spring and lined out 1 foot apart (Sheat 1953).

Division of dogwoods is carried out just before spring growth. Plants are lifted, pulled apart with small divisions, and lined out about 10 inches apart (Sheat 1953).

Transplanting flowering dogwoods with a root ball is preferred over bare-root transplanting, although both methods can be successful. Plants entering their third year are well suited for planting in permanent locations. Plants of this age are usually 2 to 3 feet tall and can be dug easily without excessive disturbance to the root system, thereby insur-

ing unchecked growth after transplanting. The transplants may be fertilized with a mixture of cottonseed meal and superphosphate in early spring at the rate of 5 to 7 trowels-full per plant (Miller 1959). Alternate-leaf dogwoods are easily transplanted with bare roots when the shrubs are less than 3 feet in height (Brush 1957). Dogwoods should be transplanted only in the spring (De Vos 1953, Wister 1950).

MANAGEMENT

Although flowering dogwood fulfills requirements of many wildlife species for food and cover, it is seldom planted for this purpose, but may be a practical means of improving wildlife habitat where fruit-producing hardwoods are scarce (Halls and Oefinger 1969). Flowering dogwood has been suggested for planting along streams, at the edge of farm woodlots, and around farm ponds (Chapman 1947a). It certainly commands attention in the management of understory plants for forest game habitat.

Silky dogwood was highly regarded by game managers for use in ruffed grouse management in southern Michigan (Zorb 1966). This shrub has been especially useful for streambank stabilization when planted in combination with grasses (Porter and Silberberger 1960). Silky dogwood has also been used successfully in strip-mine reclamation (Bramble 1952, Hart and Byrnes 1960).

Field plantings of flowering dogwood in the Northeast have not been especially successful. Survival in 22 plantings after 5 to 12 years ranged from poor to excellent, being satisfactory in only 13 plantings. Most plantings had grown only about 3 feet in 5 to 8 years. None had reached site domination or a complete canopy. Retarding factors seemed mainly to be poor soil and herbaceous plant competition (Edminster and May 1951).

In a study of flowering dogwood survival in the North Carolina Piedmont, improvement of forest soil moisture conditions was considered the most important initial step in securing satisfactory reproduction. Soil moisture conditions may be improved by the use of a heavy harrow or disk plow to break up the surface

organic matter and cut out some of the competing roots. This should be a good method for use in a good seed year, but an immediate cutting of the overstory is not desired. The result from exposing mineral soil should be a satisfactory stand of dogwood reproduction even under a fairly dense canopy. Releasing this reproduction at a later date would be important (Ferrell 1953).

Flowering dogwood may be reproduced from stump sprouts by cutting trees in late winter. Tallest dogwood sprouts have been produced by cutting in March. For discouraging dogwood sprouting, midsummer cutting is recommended (Buell 1940).

Of 59 silky dogwood plantings in the Northeast, 37 had excellent and 19 had good survival. The few failures were attributed to excessive grass competition or infertile soil. Survival was about the same from Vermont to West Virginia. After 12 or 13 years, plantings had reached heights of 8 to 12 feet on better soils but only 5 to 6 feet on some poorly drained, acid soils in New York (Edminster and May 1951). When 20-year-old plantings were checked in New York State, silky dogwood was found to have grown vigorously and dominated all the sites (Smith 1962). Survival of silky dogwood on strip-mine spoilbank plantings has ranged from 45 to 72 percent, and it is a promising species for spoilbank reclamation (Bramble 1952, Bramble and Ashley 1949, Hart and Byrnes 1960).

When silky dogwood is to be planted, 1- or 2-year-old nursery-grown seedlings are recommended. The top growth of nursery stock should be pruned back to a height of 3 to 6 inches just before planting. Like most hardwood shrubs, competition from other plants retards early growth. Hence, plantings should be made in plowed furrows or scalped sod areas. For complete site dominance, silky dogwood seedlings should be spaced 3 to 4 feet apart (Edminster and May 1951).

Use of inorganic nitrogen fertilizer has stimulated radial growth of dogwoods of various ages on soils of low to moderately low fertility. Nitrogen was applied as ammonium nitrate, 32 1/2 percent, at various rates. Marked growth response occurred the first growing season after fertilization. The response was

less favorable the second year and insignificant the third year. A nitrogen application of 500 pounds per acre resulted in almost maximum growth response (Curlin 1962).

The quality of flowering dogwood browse has been improved by controlled burning, especially burning in the spring rather than in fall or winter. Summer burning probably would be as good as spring burning. Burning increased the protein and phosphoric acid content of browse (Lay 1957).

Diseases and parasites that attack the dogwoods include noninfectious diseases resulting from an unfavorable environment, parasitic diseases, nematodes, and insects. Noninfectious diseases include sun scald, mechanical and drought injury, freezing, and improper soil nutrient balance (Beecher et al 1964). Diseases and insects may kill dogwoods, but in most cases are only detrimental to the health and vigor of the trees.

The common diseases of flowering dogwood include spot anthracnose caused by the fungus *Elsinoe corni* and *Septoria* leaf spot. The spot anthracnose fungus attacks leaves, bracts, stems, and ripe fruits and affects mostly the lower crown. The symptoms are spots about 1 mm in diameter on the blooms and leaves. Centers of the small spots fall out, giving a shot-hole appearance to the leaves. The appearance of the blooms may be seriously affected. If the disease is not controlled, it may become so severe that flower buds never open (Beecher et al 1964, Cleveland 1951). This infection can be controlled by spraying four times per year with either captan 50 percent wettable powder, 1 1/2 tablespoons per gallon of water; 3/4 tablespoons of maneb 80 percent wettable powder per gallon of water; or folpet 75 percent wettable powder at the rate of 2 tablespoons per gallon of water. The first application is made in early spring when the flower buds are beginning to open. The second spray is applied as soon as the bracts have fallen, the third spray 4 weeks later, and the fourth in late summer after the new flower buds are well formed (Beecher et al 1964).

Septoria leaf spot appears on flowering dogwood about mid-June in Virginia. It is caused by the fungus *Septoria cornicola*, which overwinters on leaves, either on the ground or on

leaves remaining attached to the tree. The symptoms are numerous small angular spots bordered by veins. The spots are purple at first, then become paler in the center, but rarely drop out. The spots may also blacken and roughen the fruit. Control consists of spraying with water solutions of captan, maneb, or zineb. Adding 1/4 teaspoon of a liquid household detergent to each gallon of spray helps insure complete foliage wetting. The first application should be made in early spring when the buds begin to open. A second application is necessary in June and a final spraying in August (Beecher et al 1964, Hepting 1971).

Additional information about these and other foliage diseases of flowering dogwood is given in a recent handbook by Hepting (1971).

Trunk canker, a stem disease most frequently found on low-vigor flowering dogwoods, is caused by the fungus *Phytophthora cactorum*. This disease is also called crown canker or collar rot. Twigs and large branches die as the disease progresses. Infected trunk tissues are discolored, and a black fluid often exudes from the canker. The canker slowly enlarges, extending completely around the base of the tree; and a collar of rot develops, eventually followed by the death of the tree. No satisfactory control for this disease is known. Small cankers, if detected in time, may be cut out and the wound dressed, but large cankers usually cannot be removed successfully. This is a disease of ornamental flowering dogwood that often follows injuries such as those caused by lawn mowers or boring insects (Beecher et al 1964, Hepting 1971).

The most common stem disease of forest-grown flowering dogwood is the target canker caused by *Nectria galligena*. Only occasional trees are infected (Hepting 1971).

The most damaging insect enemies of the dogwoods are the dogwood borers. They feed in the bark and cambium but not the sapwood. The larvae frequently kill young trees, and reduce the vitality and kill branches on older trees. Trees infested with borers have swollen areas on the trunk near the ground or at the main crotches. Since larvae enter only through a definite break in the outer bark, all

injuries to the trunk and branches of a dogwood should be avoided to prevent infestation. Pruning wounds or injuries should be treated with wound dressing. Some borers enter terminal twigs. Dead twigs should be pruned back to healthy wood and the wound dressed. The pruned twigs should be burned to destroy the borers. The trunks of newly transplanted trees may be wrapped with crepe paper to protect these trees from borer attack through unnoticed injuries. Insecticides may be used to control the overwintering borers (Beecher et al 1964, Schread 1957, Westcott 1951).

Dogwood club gall is caused by infestation with midge larvae (*Mycodiplosis alternata* Felt) and has become serious in some areas. The orange-colored maggots overwinter in the soil under dogwood trees. Pink flowering dogwoods seem to be infested most often; serious infestation will stunt the trees and kill most of the flower and leaf buds that develop beyond the galls. Excellent control of the gall may be obtained by spraying with carbaryl at the rate of 2 pints per 100 gallons of water. The spray material should be applied at weekly intervals from late May until the end of June. Trees sprayed six times were free of galls (Schread 1964).

Dogwoods are usually desirable, but certain situations may warrant control of these plants. In the South, complete control has been obtained by the application of picloram at the rate of 0.7 pounds per 100 gallons of spray. Leaf-stem application produced the best results. The degree of coverage by the spray material on thickets of dogwood was not critical (Nation and Lichy 1964). Picloram plus 2,4,5-T ester, 1½ pounds of each per acre, was also effective; 74 percent of flowering dogwoods were top-killed at the end of the second growing season after treatment (Brady 1969). But 2,4,5-T alone resulted in a lower kill of flowering dogwood, 22 percent, when helicopter-sprayed at the rate of 2 pounds acid equivalent per acre on logged and uncut areas in West Virginia (Wendel 1966).

In the South, flowering dogwood was successfully controlled by injection of 2,4-D amine concentrate (Moyer 1967) and was reported as susceptible to either 2,4-D amine or

fenuron pellets (*Cech and Mulder 1964*). However, in recent observations in West Virginia, flowering dogwood was highly resistant to treatment with fenuron (25 percent) pellets broadcast at rates of 20, 40, and 60 pounds per acre. Each treatment readily killed the overstory oaks, whereas the dogwoods responded to being released by growing and fruiting vigorously during the 4 years of observation after the treatments. This observation, and another in Pennsylvania (*Shipman and Schmitt 1971*), shows that fenuron can be used successfully to release flowering dogwood

and other shrubs overtapped by low-value hardwood trees.

Flowering dogwood is beneficial in limiting movement of nutrients (particularly calcium) through the soil profile, thus keeping them available in the rooting zone of other species (*Thomas 1967*). Having a very high content of calcium in the foliage, flowering dogwood often creates its own high soil pH. Dogwood litter decomposes very rapidly, thereby making it a prime soil builder when compared with low-calcium species such as oaks or pines (*Hepting 1971*).

GRAY DOGWOOD

GRAY DOGWOOD, *Cornus racemosa* Lam. Also called Gray-Stemmed and Panicled Dogwood.

By Stephen A. Liscinsky

*Pennsylvania Game Commission
State College*

RANGE

This species occurs in all but the northern and easternmost parts of the region. It grows from central Maine to southern Ontario and southward to Maryland, West Virginia, Kentucky, Missouri, and Oklahoma.

HABITAT

The wide range of gray dogwood indicates the many climatic conditions it will tolerate. Its ability to grow on a variety of sites is equalled by few other shrubs. In central Pennsylvania alone it is found from moist lowlands to dry uplands in medium- to heavy-textured soils (Heyl 1954). The top 4 inches of soil in these Pennsylvania sites had the following ranges in characteristics: pH 4.6 to 7.8; percentage organic matter 1.3 to 5.0; phosphorous 0.0 to 7.5 ppm; and potassium 15 to 338 ppm (Heyl 1954).

Gray dogwood is most commonly found growing in thickets along fencerows and woods edges and in abandoned fields. Although found mostly in pure thickets, it will persist for a considerable time in mixtures with other species. Hawthorns, elms, and ashes are common overstory associates, while grasses, sedges, goldenrod, and cinquefoil are common ground cover companions (Liscinsky 1960).

LIFE HISTORY

In June or July the shrub is often covered with small pyramidal clusters of little creamy-white blossoms, which are followed in September and October by showy clusters of white berry-like and brightly red-stalked fruits. If not eaten by wildlife, the fruit persists long after the leaves have fallen. Gray dogwood is well known for producing good to heavy crops of seed annually. Dissemination of the seed is largely credited to wildlife, especially birds.

Gray dogwood thickets seem to originate at a central point from seedlings that in turn spread by means of root suckers.

Gray dogwood is a slow-growing shrub. At 10 years of age a stand of gray dogwood is seldom more than 6 feet in height, with maximum stem diameters of 1 inch. At about 20 years it reaches its maximum height of 9 feet and stem diameters up to 1½ inches. Maturity is reached at this time, and the stand either gives way to more tolerant, longer-lived species, or regenerates itself if there is no competition. Stand density decreases from 120 to 20 stems per 100 square feet from ages about 5 to 15 years (Liscinsky 1960).

Tolerance to shade is considered intermediate. Removal of some overstory competition has been found beneficial to gray dogwood.

USE BY WILDLIFE

The fruits of gray dogwood are readily eaten by wildlife, especially by birds. Gray dogwood is an important cover plant for woodcock and ruffed grouse. Woodcock use thickets of gray dogwood from spring to fall for nesting, feeding, and resting. Grouse may be flushed from these thickets at any time of the year, but there is no record of nesting in them. For food and cover for wildlife, and its many other desirable attributes, gray dogwood is a highly desirable plant for wildlife. Deer browse the plant, but it is low on the preference scale.

PROPAGATION

Seed and stock are usually available commercially, but less available than other dogwoods such as flowering and silky dogwoods. Seeds average about 12,000 per pound, and average germination in tests was 31 percent, though a potential of 50 to 75 percent can be expected (*U. S. Forest Service 1948*). Dogwood seeds are dormant and require several months of warm, moist treatment before cold stratification for satisfactory germination (*Heit 1968*). The ideal way to handle the species is to collect mature fruit, clean the seeds, and plant them in early August (*Heit 1968*). In one case, seeds collected green in July and sown immediately gave full germination the next spring. Cleaned seeds may also be stratified and held for planting in April or early

May. For long-term storage, seeds should be cleaned, air-dried at low humidity, placed in sealed containers and kept at 34 to 38°F (*Heit 1967e*). Seed stored this way will retain excellent germination and vigor for 4 to 8 years (*Heit 1967e*).

The seeds are usually sown in drills, sometimes broadcast, and are covered with $\frac{1}{4}$ to $\frac{1}{2}$ inch of soil. Forty seeds per square foot are recommended (*U. S. Forest Service 1948*).

I had some success in planting 1-year-old seedling stock, but recommend 2-year-old stock. Success was definitely better on the more fertile soils and where the sod was removed before planting (*Liscinsky 1960*).

Generally speaking, success in planting this dogwood has not been as good as with others. However, most dogwoods can be grown from seeds, from root cuttings, by layering, and by division (*U. S. Forest Service 1948*).

MANAGEMENT

Management of this species is not difficult. Emphasis should be placed on caring for stands that become established naturally. This involves provision for some direct sunlight and elimination of some competing trees. Growing in thickets, adjacent to hawthorn and alder patches, this species is especially beneficial to wildlife. Establishment by planting should be reserved for areas where no gray dogwood exists and where the soil is suitable.

RED-OSIER DOGWOOD

RED-OSIER DOGWOOD, *Cornus stolonifera* Michx. Also called Harteres Rouges, Kinnikinnick, Red-Stemmed Cornel, and Squawbush.

By Margaret Smithberg
*University of Minnesota
St. Paul*

RANGE

Red-osier is most common in glaciated areas of the northeastern and midwestern states and provinces. South of the glaciated areas, it occurs locally near Washington, D. C., and in West Virginia, Ohio, Illinois, Indiana, Iowa, and Nebraska.

HABITAT

Although optimum conditions for the species have not been described, red-osier dogwood is somewhat restricted by high temperatures. Its southernmost limit is Washington, D. C., while in Canada it extends up to the tundra lines.

The species is characteristic of swamps, low meadows, and river and creek banks. However, it is also found commonly in drier situations such as fields and woods borders and may be cultivated in drier soils (Grimm 1952).

It is highly adaptable to soil type, being found for example on rich-woodland soil, silt loam, fine sandy loam, poorly drained muck, gravelly sand, boulder till clay, sandy upland soil, calcareous gravel, dolomite sandstone, heavy clay with peat, bottomland silt, and dry humus peat.

Red-osier dogwood, as a dominant member

of "edge" vegetations, is also adaptable to soil reaction. It is tolerant of alkaline soils (Van Dersal 1938) and was found in a wide range of pH values: 8.0 near lake outlets, 6.0 for sedge and northern white-cedar swamps, and 3.2 for sphagnum mats (Jewel and Brown 1929).

Since red-osier dogwoods growing in the poorer soils are likely to grow slowly and produce less fruit, the characteristics of soils that yield vigorous growth are more useful in choosing high-quality planting sites or suitable nursery soils. A Wisconsin sampling of vigorous stands led to these soil fertility standards for red-osier dogwood: pH 5.0-6.0, base exchange capacity 6.0 M.E./100 g., total nitrogen .07 percent; and these amounts of nutrients in pounds per acre: N-15, P₂O₅-75, K₂O-150, and replaceable calcium-1,200 (Wilde 1946).

The species plays a major role in many plant communities. It is commonly present along stream banks and shores with alder, birch, and willow, and is a dominant in wet lowlands with sedges, poplars, and black spruce. It is one of the earliest shrubby plants to become dominant in bogs and swamps, due to its ability to live with its roots often immersed in water (Conway 1949).

In moderately moist situations, it is found

with mountain maple, alder, meadow rose, and blackberries. It often invades grasslands, where it produces single, very large plants (*Stallard 1929*). Along forest margins, between forest and moist areas especially, it assumes an invader's role, as do hazel and gray dogwood. But where the latter two remain marginal, the red-osier dogwood soon extends into the moister regions.

LIFE HISTORY

Flowering occurs in May-June, but second flushes of bloom are common in late summer. The fruit, which is white to lead-color, ripens from July to early fall. The seed may germinate in the following spring or may lie over until the second spring.

Data are not available on the age for commercial seed-bearing (*U. S. Forest Service 1948*). The typical ages of first fruit-bearing, among unshaded or lightly shaded plants in Connecticut, were 4 years for wildlings and 3 years for nursery stock. Fruit yields were small compared to older plants (*Spinner and Ostrum 1945*). Little is known about geographic differences in seed production; however, in a species with such a wide distribution it is quite likely that differences exist.

Number of cleaned seeds per pound varies: 13,800 to 26,700 (*U. S. Forest Service 1948*) and 17,300 (*Van Dersal 1938*). The seed is heavy and is thus spread mostly by birds.

The species reproduces in a number of ways. As its specific name denotes, it produces stolons (runners). In a study in various habitats, this form of reproduction was noted primarily in very moist situations and in wet sedge meadows (*Smithberg 1964*). Reproduction also occurs from stems touching or growing under the ground, from seed, and even by shoot growth from roots. It was observed that when a branch is near death, a new branch may arise from the base of the old one. This occurrence accounts for the large many-stemmed forms often found.

Growth is fairly rapid. An average plant measured at the end of the first growing season, under clean cultivation, grew 443 inches of twigs (1,125 cm among all branches over three cm long) (*Smithberg and Weiser 1968*).

The average plant height the first season was above 3 feet.

When found in meadows with close grass cover, the species tends to remain in single large plants, because layering cannot occur.

Light intensity no doubt plays an important role in limiting the spread of red-osier dogwood. It is suppressed in shade and thus is never a dominant understory plant (*Spector 1956, Stallard 1929*). Under shade conditions it often reaches a height of more than 10 feet.

USE BY WILDLIFE

The species is commonly browsed by deer (*Dahlberg and Guettinger 1956, Meagher 1958, Murie 1951, Smith 1964*). I noted in Minnesota that the species was preferred over gray dogwood when they were found growing together.

At Isle Royale in Lake Superior it is an important winter browse for moose (*Hosley 1949*). In Montana it is browsed extensively by elk, in winter, and by mountain goats (*Murie 1951*). Black bear and beaver include it in their diet (*Martin et al 1951, Rue 1964*), as do mule deer, cottontail rabbit, and snowshoe hare (*Van Dersal 1938*). Fruit, wood, and foliage are utilized.

Red-osier also provides food for many songbirds and upland game birds. In New England it was found in the diet of 93 different bird species (*McKenny 1933*). It is a favorite fall food of ruffed grouse (*Bump et al 1947*) and is one of the preferred foods of both pheasant and turkey (*Korschgen 1960*).

The fruits of the species are readily identifiable in stomach analyses because of the unique two-celled character of the nutlets.

Red-osier dogwood is an important cover species for birds. In a study of vegetation and animal use of power line rights-of-way, the species provided dense summer cover, and the winter stems provided partial cover (*Gysel 1962*). It is an important cover for pheasant (*Korschgen 1960*) and is commonly found near ruffed grouse drumming logs in lowland vegetation types (*Palmer 1961*).

In fishery management, red osier is recommended for streambank plantings to stabilize eroding banks and to provide shade and cooler

water for summer protection of fish (*Black 1954*).

PROPAGATION

Plants of *Cornus stolonifera* are often available commercially. However, *Cornus alba sibirica*, a very closely related plant, is much more common. Some taxonomists feel that the two are one species, *Cornus stolonifera* on this continent being a geographic variant of the Eurasian *Cornus alba*.

Propagation is possible either from seed or cuttings, and each source can be handled in various ways. With seed, the first option is fall versus spring sowing. Though this choice will usually be made before seed collection, the collection, cleaning, and storage of seed should be about the same in either case. Fruits should be collected when fully ripe (late July-October), because plantings of immature seed have shown reduced germination. If viability testing is to be done, red-osier, along with other dogwoods, requires use of embryo excision, tetrazolium chloride, or other special cutting tests (*Heit 1967c*). Cutting-test results in the range of 80 to 92 percent have been reported (*Swingle 1939*).

Seeds should be cleaned and air-dried if they are to be stored. The yield of cleaned seed is 15 to 20 pounds per 100 pounds of fruit, and the number of cleaned seed per pound averages about 19,000 (*U. S. Forest Service 1948*).

Fall sowing can be done in September-October or earlier. If dry, the seeds should be soaked, at least, before planting (*Heit 1968*). Soil recommendations are given in the life history discussion above.

The spring planting option requires storing and stratifying the cleaned, dried seed. Storage in sealed glass containers at 34 to 38°F for 4 to 8 years produced good germination, after stratification. The seeds have an embryo dormancy, which can easily be broken by stratification in sand, peat, or a mixture for 90 to 120 days at 41°F (*U. S. Forest Service 1948*) or longer, 120 to 140 and up to 290 days at 32° to 50°F (*Chadwick 1935, Laurie and Chadwick 1931*).

Some lots of seed may have hard-coat as well as embryo dormancy obstacles to germi-

nation and may require mechanical scarification before stratification (*U. S. Forest Service 1948*). Hard seed that has not been scarified may not germinate until the second spring after planting (*Laurie and Chadwick 1931*). Germination-test results have ranged from 6 percent for untreated seed (*Swingle 1939*) to 76 percent for stratified seed (*Chadwick 1935, U. S. Forest Service 1948*).

In the nursery, seeds are usually sown in drills at the rate of 40 viable seeds per square foot and are covered with $\frac{1}{4}$ -inch of soil. The beds are usually mulched with leaves or straw, which is removed at the first sign of germination (*U. S. Forest Service 1948*). In one case, the yield per pound of cleaned seed was 2,979 plants when seed was spring-sown after stratification for 155 days at 40°F (*Swingle 1939*). One-year-old stock is usually large enough for outplanting (*U. S. Forest Service 1948*).

Use of cuttings or layering are practical alternatives to propagation from seed. Both softwood and hardwood cuttings root satisfactorily (*Laurie and Chadwick 1931*). No treatment of the cutting material is necessary. Cuttings taken in early August rooted 100 percent in 5 weeks. Hardwood cuttings taken in mid-April and immediately set in the field rooted 90 percent in 8 weeks (*Doran 1957*). A wholesale nursery in Minnesota takes hardwood cuttings either in the fall or spring, plants them in $1\frac{1}{2}$ x 2-foot spacing in sandy loam beds, irrigates only when necessary, and obtains about 60 percent rooting. The cuttings are ready for transplanting after one growing season (*Gordon Bailey, personal communication*).

Although treatment is not essential, over 90 percent rooting was obtained in hardwood cuttings 6 to 8 inches long which were dipped in indole butyric acid (500 ppm in talc), planted in sand, and intermittently mist-sprayed (*Smithberg 1964*). Sand was a better rooting medium than peatmoss for potted cuttings of various dogwood species (*Vermeulen 1959*).

Layering is also a common practice. Branches are held to the ground with hooks and covered with loose soil. Rooting occurs after several weeks. A shoot rooted in this manner is merely cut from the parent plant and transplanted to the desired location (*Hartmann and Kester 1959*).

MANAGEMENT

The ease by which the species can be propagated and its fairly rapid growth on open moist sites makes it a desirable choice for streambank planting and wildlife cover adjacent to farm ponds (*Chapman 1947a*). It is also commonly used for windbreaks, gullies, and field and woodland border plantings (*Graham 1947*).

Planting trials in New York led to conclusions that red-osier can be used interchangeably with silky dogwood (*C. amomum*) in all

but the driest sites. Red-osier fruited more abundantly and somewhat later than silky dogwood, but not enough later to provide winter food for wildlife. Most of the wildlife use of both species apparently was feeding by songbirds. Both species showed good survival and growth (*Smith 1964*).

Red-osier dogwood can be controlled by spraying mixtures (in either oil or water) of 2,4-D and 2,4,5-T. Mixtures of dicamba and either 2,4-D or 2,4,5-T have also been recommended.

ELDERS

AMERICAN ELDER, *Sambucus canadensis* L. Also called Blackberry Elder, Common Elder, Elder, Sureau Blanc, and Sweet Elder.

SCARLET ELDER, *Sambucus pubens* Michx. Also called Red or Red-Berried Elder, Stinking Elder, and Sureau Rouge.

D. Michael Worley

*Ohio University
Athens*

and

Charles M. Nixon

*Ohio Department of
Natural Resources
New Marshfield*

RANGE

Both species occur throughout most of the Northeast. Scarlet elder is more widely distributed northward, from Newfoundland to Alaska, but becomes localized southward, notably in northern Ohio swamps and the Appalachian highlands of West Virginia and Kentucky. American elder ranges from Cape Breton west to Manitoba, and south to Georgia, Louisiana, and Oklahoma (Braun 1961, Fernald 1950, Gleason 1963c).

HABITAT

Each species grows under a variety of conditions so that one or the other is acclimated to practically all the extremes that occur in the Northeast. Scarlet elder is less adapted to warmer climates than American elder and southward becomes localized to the cooler uplands or swamp forests (Braun 1961).

Both species tolerate saturated soils. American elder usually occupies well-drained slightly acid soil (pH 5.5 to 6.0) bordering streams and in the adjacent bottomlands, but

also grows on gray forest soils and muck (Laurie and Chadwick 1931). Horticultural varieties of American elder succeed best in rich, moist, sandy soils (Judkins 1945). American elder has been found growing up to 4,000 feet in the southern Appalachians (Ritter and McKee 1964).

Scarlet elder grows in circumneutral soils (pH 6.0 to 8.0) and is somewhat more tolerant of dry soils and somewhat less adapted to saturated soils than American elder. Scarlet elder is often found on rocky soils (Hottes 1931), and in the Adirondacks is usually found where mineral soil has been exposed (Webb 1959).

American elder ranges almost throughout the eastern deciduous forests (Braun 1961). In upland mixed, moist-site communities, it is associated with witch-hazel, maple-leaved viburnum, ironwood, spicebush, and hophornbeam, and is most commonly found in the early successional types. In bottomlands, willow, alder, sycamore, and elm are common associates (Braun 1950). In oak-hickory communities, American elder is associated with hazelnut, spicebush, wild hydrangea and coral-

berry; and in the oak-chestnut community with gray dogwood, rose, New Jersey tea, and grape (Braun 1950).

Scarlet elder is seldom found south of, or lower in elevation than, the beech-maple forest zone, and in the southern portions of the region is restricted to higher altitudes in this community (Braun 1961). Scarlet elder is also associated with the hemlock-white pine-northern hardwood communities. Shrub species found with scarlet elder in these forests include American fly honeysuckle, beaked hazel, hophornbeam, and winterberry (Braun 1950). In the beech-maple and spruce forests of the Appalachian highlands, striped and mountain maple, hobblebush, and winterberry are common shrub associates (Braun 1950).

LIFE HISTORY

Both species bear separate male and female flowers on the same plant. Flowers usually occur on second-year and older canes and are arranged in clusters of compound cymes. Scarlet elder flowers from April through May, and the fruits ripen from June through August. American elder flowers from late June into August, and the fruits ripen from late July into September. Seed dispersal occurs from July to October in American elder and June to August in scarlet elder (Park 1942, U. S. Forest Service 1948).

American elder usually bears seed on second-year and older canes, but horticultural varieties grown from seed will occasionally fruit the first year (Ritter and McKee 1964). In Connecticut, wildlings first bore fruit at 3 years of age (Spinner and Ostrom 1945). The life span of individual canes is 3 to 5 years (Deam 1932). No information is available on youngest or oldest seed-bearing age of scarlet elder.

Information about fruit production is sketchy. In West Virginia, both elder species were checked during four consecutive years. There were no crop failures, and 70 to 80 percent of the plants bore fruit. Among 19 plants of comparable sizes, averaging 0.40 to 0.47 inch dbh, American elder produced about five times as much fruit, by volume, as scarlet elder (Park 1942). Scarlet elder may have alternate light and heavy fruit crops, and may

be more variable in fruit yield than American elder (U. S. Forest Service 1948).

Seed dissemination for both species is usually through ingestion by birds and mammals. Passage through pheasants inhibited seed germination of American elder, but passage through song birds increased subsequent germination (Krefting and Roe 1949).

Elders reproduce from seeds, sprouts, layers, and root suckers; but establishment in new areas comes mainly from seed. Once established, runners of both species tend to persist through vigorous resprouting (Ritter and McKee 1964). Seedling growth is rather slow during the first year; seedlings of American elder grew only 2 inches in 45 days (U. S. Forest Service 1948). After the first year, growth is rapid for individual canes of both species, often as much as 15 feet (Ritter and McKee 1964). Sprout growth is much more rapid than growth from seed, and is most rapid in the first year after sprouting. Mature plants average 3 to 10 feet in height.

American elder grows best in full sunlight; scarlet elder is more shade-tolerant (Chapman 1947e). Once established, both elders soon outdistance herbaceous competition. Thickets of both species are replaced by more shade-tolerant species during the later stages of forest succession, but individual plants and small runners will persist under a forest canopy.

USES

At least 50 species of song birds relish the fruit of American elder during summer and early fall, and at least 25 species eat the fruit of scarlet elder during the summer (Van Dersal 1942). Wild turkey, bobwhite, quail, mourning doves, ruffed grouse, and ring-necked pheasants also eat the fruit during late summer and early fall (Martin et al 1951, Van Dersal 1938) as do red squirrels, rabbits, woodchucks, foxes, opossums, skunks, chipmunks, whitefooted mice, and raccoons (Chapman 1947e, Martin et al 1951). White-tailed deer feed on twigs, foliage and fruit of both species during the summer (Martin et al 1951), and moose have been observed browsing scarlet elder (Van Dersal 1938). American elder rates higher on deer food preference lists from four northeastern states than on those

for southern states. Samples of American elder, collected in Louisiana and North Carolina, had higher percentages of crude protein (leaves 18, stems 7, and fruit 14) than most other browse plants (*Hankla 1961*).

New growth of American elder contains a glucoside that is occasionally fatal to livestock (*Hankla 1961*) and may influence deer utilization of elder. In the northern Lake States, a clipping study of scarlet elder showed erratic responses to heavy clipping in November. Capacity of the plants to withstand browsing was about equal to that of red-osier dogwood and mountain ash. Elders should be only moderately browsed each year (*Aldous 1952*). Cottontail rabbits, woodchucks, and red squirrels have been observed feeding on the bark of common elder during fall and winter (*Martin et al 1951*).

Elders provide fair escape cover for wildlife; and American elder has been ranked outstanding, along with grape and bittersweet, as nesting cover for small birds (*Petrides 1942*). American elder is thicket-forming, but the foliage of individual plants is quite open and the stems are bare. Scarlet elder is less apt to form thickets and offers less cover. However, during summer, the partial shade under American elder promotes a dense ground cover of grasses and forbs that offers good loafing or feeding areas for broods of young pheasants and quail (*Chapman 1947e*). In Ohio, elder thickets in bottomlands are often used by ruffed grouse broods during summer. In northern Ohio, wintering flocks of mourning doves roosted in a mixture of elder, sumac, blackberry, and dogwood found in openings within a pin oak stand (*Hennessy and VanCamp 1963*).

Both elders have been recommended and used for wildlife purposes in landscaping home grounds and roadsides (*Curtis and Wyman 1933, Holweg 1964*). Elderberries, of course, are also attractive to makers of pies, jams, and wine.

PROPAGATION

Seeds or rooted cuttings are available commercially, particularly for American elder, but seeds are not usually utilized for commercial propagation (*Mahlstede and Haber 1957*). Wild seed can be harvested from July through

September and should be collected as soon as fruits ripen. Commercial seed consists either of dried fruit or clean seed. Seed soundness and purity for American elder averaged 80 and 92 percent respectively. For scarlet elder, soundness averaged 97 percent and purity 98 percent (*U. S. Forest Service 1948*).

Fruit of American elder contains three to five one-seeded nutlets (*Krefting and Roe 1949*). Yields of cleaned seed per 100 pounds of fruit were 7 to 18 pounds for American elder (14 samples) and 4 pounds for scarlet elder (6 samples). Average numbers of cleaned seed per pound (14 samples) were 232,000 for American elder and 286,000 (6 samples) for scarlet elder; ranges were 175,000 to 324,000 and 192,000 to 377,000 respectively (*U. S. Forest Service 1948*). Cleaned and dried seeds of both species showed little or no loss in viability after nearly 2 years of storage in sealed containers at 41°F. Scarlet elder seed also retained viability for 1 year when stored in moist sand at 41°F (*U. S. Forest Service 1948*).

Seeds of both species exhibit variable degrees of hard-seededness and embryo dormancy. Scarlet elder is more difficult to germinate than American elder, but both require pretreatment for good germination during the first year. As preparation for spring sowing, seeds can be scarified with sulfuric acid for 10 to 20 minutes (American elder) or 10 to 15 minutes (scarlet elder), washed, and then pre-chilled at 36 to 40°F for 2 months (*Heit 1967a*). As an alternative to the acid treatment, a warm/cold stratification in moist sand was effective for American elder. The sequence was 60 days at 68 to 86°F alternating daily, then 120 days at 41°F. A longer period of cold stratification, 150 days, was less desirable because seeds began to germinate at 41°F after 120 days. Also, freshly collected seed showed less dormancy than seed from dried fruit (*Krefting and Roe 1949*).

Scarlet elder seed may germinate more uniformly if given a combination of the treatments above; acid scarification, 3 to 4 months of warm stratification, and 2 months of moist prechilling (*Heit 1967a*).

For late summer or fall sowing of fresh seed, acid treatment, as described above, should im-

prove germination in the following spring. Untreated seeds sown in late fall ordinarily do not complete germination until the second year (Heit 1967a). Fall-sown seedbeds should be well mulched because freezing does not favor after-ripening and may kill seeds that have imbibed water (Davis 1927).

American elder seed can be sown in drills, 35 viable seeds per linear foot, and covered with $\frac{1}{4}$ inch of soil. Germination rates as high as 80 to 85 percent have been attained. Beds of scarlet elder seedlings should be given half shade (U. S. Forest Service 1948).

Elders can also be propagated from hardwood cuttings taken from vigorous 1-year-old canes. Cuttings should vary in length from 10 to 18 inches, include 3 sets of opposite buds, and be taken in the spring as soon as the ground can be worked (Ritter and McKee 1964). Cuttings may also be taken in the fall, placed in moist peat or sphagnum moss, and held in cold storage at approximately 40°F for spring planting (Mahlstede and Haber 1957).

One-year-old seedlings or rooted cuttings of both species are usually large enough for field planting (U. S. Forest Service 1948). American elder should be planted in moist, rich, slightly acid soil, preferably in low swampy areas in a sunny location. No information is available about success of direct-seeding or the pretreatment of planting areas. If herbaceous growth is rampant, scarification should improve seedling survival. Scarlet elder is more tolerant of shade and soil conditions and may be planted on a variety of sites. However, in the southern portions of the Northeast, scarlet elder may not succeed at lower elevations or away from the beech-maple community (Braun 1961).

MANAGEMENT

Elders may serve best as nesting cover and a summer and early fall food source for birds. American elder seems superior to scarlet elder for such purposes, but is more demanding in its site requirements. Mixtures of the two species may be desirable, particularly where the site is partly shaded or the soil is less moist than that preferred for American elder. Mixtures are also recommended for contrast in decorative landscape plantings—particularly as tall background shrubs in fairly moist, partly shaded locations (Curtis and Wyman 1933). Pond and stream margins are among the best locations for both species (Chapman 1947e).

American elder can be used, at least partly, for erosion control on moist sites. It pioneers on some strip-mine spoils and may occasionally be useful for reclamation planting (Chapman 1947e).

Experience with cultivated varieties of American elder has shown that annual pruning will considerably improve fruit yield. Pruning should aim to leave five to six strong, 1-year-old canes and one or two older canes per runner. Removal of terminal shoots and dead canes will reduce winter-kill of terminal shoots and help control elder borers (Ritter and McKee 1964).

Both species fruit best in full sunlight, although scarlet elder will produce some fruit under a fairly dense canopy. Shading should be controlled if maximum fruit production is desired. Once established, the elders seem to outdistance herbaceous competition.

For wildlife management purposes, elders would seldom need to be killed; but they are susceptible to control by AMS or 2,4,5-T. They are intermediate in susceptibility to 2,4-D, and resistant to Amitrol, diuron, fenuron, and monuron (Dunham 1965).

SUMMER GRAPE

Vitis aestivalis Michx. and
Vitis aestivalis var. *argentifolia* (Munson) Fern.

Also called Blue, Bunch, Pigeon, and Silverleaf Grape.

By Lynn M. Shutts

USDA Soil Conservation Service
Moorefield, West Virginia

RANGE

Summer grape (including the variety *argentifolia*) ranges northward as far as southern New Hampshire to southern Minnesota—but not into Canada—and southward to Georgia and Texas. It is uncommon near the northern limits of its range. In West Virginia, summer grape is the most common grape species, and the variety *argentifolia* is nearly as abundant as the typical form (Fernald 1950, Massey 1961, Strausbaugh and Core 1958).

HABITAT

The optimum climatic conditions for summer grape have not been described, but grapes are subject to both cold and heat injury. A sudden temperature rise in late spring may result in damage to shoot tips. Spring frosts often damage foliage if warm weather and rapid growth precede a sudden temperature drop. Grapes do best under the moderately moist conditions necessary for adequate growth and resistance to disease. The primary damaging effect of excess moisture (rain or high humidity) is the enhancement of fungous diseases that destroy the fruit.

This species is generally restricted to upland areas (Hedrick 1908). The vines do well

on light, easily crumbled, shallow soils of old formation (Viala and Ravaz 1903). In Virginia, summer grape was found growing over a wide range of soil and site conditions (Shutts 1968). The pH requirements are variable.

Vines often occupy moist bench areas or ravines on southeastern slopes where organic matter has accumulated. Common associates are those species that occupy cove sites. Individual vines have been observed climbing in practically all species of hardwoods and conifers that occur within the range of summer grape.

LIFE HISTORY

The species bears male and female flowers on separate plants, and the flowers bloom from May through July. Pollen is disseminated by wind and rain. The fruit ripens to a dark purple in September or October (Massey 1961). Seeds are disseminated by wind action and by animals.

The plant is capable of producing seed the third season after establishment. The fruit crop is variable and often fluctuates greatly from year to year, but good crops occur in most years. Six vines with diameters ranging from 0.8 to 2.1 inches produced a total of 9,-

334 individual grapes in one season. Approximately 40 percent of these grapes were affected by black rot fungus, which reduced their food value. The number of bunches per vine increased with the diameter of the vine (*Shutts 1968*). Dropping of fruit from the vines peaked during the first 2 weeks of November in the Ridge and Valley Province of Virginia (*Shutts 1968*).

Grapes may reproduce by means of seeds, sprouts, or layers. Terminal growth is very rapid, but lateral growth is slow. A vine 50 years old may have a diameter at ground level of only 1.5 inches.

The effects of sunlight on establishment are unknown. However, woodland openings, such as those produced by windfall or logging, appear to accelerate growth.

USE BY WILDLIFE

Black bear, raccoon, bobwhite quail, ruffed grouse, wild turkey, and a host of song birds eat grapes (*Martin et al 1951*). Deer browse the foliage and stems in the spring and early summer, and may consume large quantities of fallen leaves during the winter months (*Massey 1961*).

In summer, grape stands provide excellent escape and nesting cover for song birds. The vines may be so twisted and tangled as to effectively exclude predators.

Birds often use the stringy bark in nest construction (*Martin et al 1951*). Gray squirrels also build leaf nests with grape vine bark, and trees with grape vines in them appear to be preferred sites for leaf nests.

PROPAGATION

Seed is not available commercially, but may be collected in fruit traps made of polyethylene (*Shutts 1968*). Seed collection may be accelerated by shaking the bunches from the vines during late October and early Novem-

ber. During years of heavy fungus attacks, seed may be only 50 percent sound.

Grape seeds are not difficult to germinate, but plants raised from seeds may not be true to type (*Hartmann and Kester 1968:384; Hosley 1938:339*). Seed should be cleaned, stratified over winter, and planted in early spring. Good results have been obtained with a commercial species (*V. vinifera*) after a moist stratification period at 33 to 40°F for about 12 weeks before planting (*Hartmann and Kester 1968:385*). After 1 year in seedbeds, seedlings can be transplanted to permanent locations (*Massey 1945*).

Probably the most effective method of propagation is layering in early spring, because this produces new plants of known sex. Plantings should have at least one male plant for every three or four female plants (*Massey 1961*). Cuttings are low in rooting efficiency (25 percent). Grafting can be used to increase fruiting vines or pollen-producing vines where an improper balance is evident (*Massey 1945*).

MANAGEMENT

Summer grape is well adapted to grow in a variety of special situations such as over stone walls, rock piles, fences, spoil banks, or up over trees of poor quality (*Hosley 1938:337*). It could be used in most forest situations where production of wildlife food and cover were of primary importance. Grape stands may be effective in concentrating turkeys and grouse for harvest because the peak of fruit fall usually occurs in early November.

The best methods of maintaining grape stands are not yet known, but U. S. Forest Service studies about maintenance of grape stands have been initiated on the Jefferson National Forest, New Castle, Va. Grapevines are best controlled in large timber by severing the vines at their base. In small timber the herbicide 2,4,5-T can be applied as a foliage spray.

GREENBRIERS

COMMON GREENBRIER, *Smilax rotundifolia* L. Also called Bamboo-Brier, Biscuit-Leaves, Bread and Butter, Catbrier, Common Bullbrier, Devil's Hop Vine, Horsebrier, Hungry Vine, Roundleaf Greenbrier, Sowbrier, and Wait-a-Bit.

CAT GREENBRIER, *Smilax glauca* Walt. Also called Catbrier, Glaucous-Leaf Greenbrier, Sawbrier, Sarsaparilla Vine, and Sowbrier.

WITH NOTES ON
SAW GREENBRIER, *Smilax bona-nox* L.
LAUREL GREENBRIER, *Smilax laurifolia* L.

By Robert L. Smith
*West Virginia University
Morgantown*

RANGE

Eleven species of greenbrier occur in the eastern United States and Canada, but most grow primarily in the South; and only four species are considered here.

Common greenbrier is widely distributed throughout the East, from Nova Scotia to southern Ontario and Illinois, south to Florida and Texas. It is most common in the northeastern part of its range (*Gleason 1963*).

Cat greenbrier, the second most common species, has a more southern distribution, the northern edge of its range reaching into southern New England and New York, eastern Pennsylvania, and southern Ohio (*Fernald 1950*); it is most common in the southern part of its range (*Gleason 1963a*). Bristly greenbrier is widespread in the Northeast, but is

seldom abundant and is not discussed here because little information about it was available.

Saw greenbrier is chiefly a southern species that extends northward along the coast to Maryland and Delaware. Laurel greenbrier, an evergreen, is primarily a coastal species in the Northeast, occurring only along the coasts of Virginia, Maryland, and New Jersey (*Fernald 1950*).

HABITAT

The greenbriers are adapted chiefly for southern climates. In the North they are found principally on warmer and drier west- and south-facing slopes. Common greenbrier is the most common species in the Northeast; it grows on a wide range of sites from moist to well-drained to dry, although in the south it is

most abundant in low, damp flatwoods (*Goodrum 1961*). The optimum soil pH was reported as 5.0 to 6.0 (*Spurway 1941*). Cat greenbrier and saw greenbrier grow in a variety of soils and moisture conditions (*Goodrum 1961*), but in the Northeast cat greenbrier is characteristic of dry, well-drained soils (*Braun 1950*). In the highly dissected mountains of southwestern West Virginia, common greenbrier is widely distributed on south slopes and grows over the ridgetops and onto upper north slopes, but cat greenbrier is confined to south-facing slopes (*W. A. Van Eck and R. L. Smith, unpublished data*). Laurel greenbrier occurs mostly in low, wet grounds and swamps. It is most abundant in the bogs and pocosins near the coast from New Jersey to Florida (*Oosting 1956*).

Both common and cat greenbrier are pioneering successional species as well as components of forest understory vegetation. They commonly invade old fields, where they may be associated with sumacs, St. John's wort, black locust, sassafras, blackberry, blueberry, and bracken fern; and they remain a part of the understory when forest claims the site. Common understory associates are witchhazel, mapleleaf viburnum, grape, and flowering dogwood (*R. L. Smith, unpublished data*).

Although most greenbriers grow well in the shade, they generally do not grow or mature as rapidly, or produce as much fruit, as plants in the open (*L. K. Halls 1968, unpublished report*). Common greenbrier is more shade-tolerant than cat greenbrier, and good fruit crops have been noted in West Virginia for common greenbrier in 70 to 80 percent shade. Both species usually achieve maximum growth and produce the most fruit along the forest edge and in forest clearings where better moisture conditions may compensate for shading, or in old fields where they may cover the ground with dense spiny tangles. In Texas, young common and saw greenbrier plants yielded 11 or 12 times more browse in the open than in heavy shade from pines (*L. K. Halls 1968, unpublished report*). No such data for intermediate levels of shading are available; but in the Northeast, common greenbrier, at least, grows better than cat greenbrier in partial shade.

Shading of about 10 to 20 percent may be optimal for common greenbrier.

In the woods, common and laurel greenbrier tend to climb into trees. In the Northeast, common greenbrier rarely overburdens the supporting trees, and it seldom interferes seriously with tree or shrub regeneration. Cat greenbrier, however, often dominates other woody vegetation in old fields.

LIFE HISTORY

The greenbriers are climbing vines supported by tendrils that grow in pairs from the axils of the leaf. The male and female flowers, small and greenish yellow or white, are borne in small clusters on separate plants. In the Northeast, common and cat greenbrier bloom in May and June, and saw greenbrier from May to July. Laurel greenbrier flowers later, August and September, and its fruit does not ripen until October of the following year (*Fernald 1950, Gleason 1963a, Van Dersal 1938*).

The fruits of common, cat, and saw greenbrier ripen during September and October, the first year, into black berries covered with a whitish bloom. The fruit of common greenbrier usually contains 1 or 2 seeds, but may have 4. Cat greenbrier fruit may also have 0 to 4 seeds but usually has 1 to 3 (*F. L. Pogge, unpublished data*). In Connecticut, cat greenbrier fruited first at age 2 years among wild plants and at 1 year in nursery-grown vines (*Spinner and Ostrom 1945*). The canes, which live for 2 to 4 years, produce flowers after the first year, usually on the annual shoot growing from the upper part of the cane (*Goodrum 1961*). Fruits usually persist on the vines into the winter (*Park 1942*). Cat and common greenbrier fruits often persist until the next summer.

The fruits of common and cat greenbrier consist of about equal weights (oven-dry) of fruit pulp and seed (*L. K. Halls 1968, unpublished report*). Chemical analysis percentages for seed collected in Rhode Island and air-dried were, for common and cat greenbrier respectively: protein 9, 11; fat 5, 8; crude fiber 19, 18; nitrogen-free extract 61, 57; ash 3, 3; and water 3, 4 (*Wright 1941*). Leaves and browse-stems of common greenbrier collected in North Carolina, Maryland, and Louisiana

have been similarly analyzed. Crude protein percentages ranged from 7 to 16 percent and varied with season and site factors as follows:

Higher	Leaves	Spring	Burned site	Open site
Lower	Twigs	Fall	Unburned	Woods

Fat content was generally low, 2 to 4 percent, except for one sample (6.1 percent) of leaves from Louisiana (*Blair and Epps 1969; DeWitt and Derby 1955; Halls and Epps 1969; Smith et al 1956*).

Although greenbriers reproduce by seed, common, cat, and saw greenbriers spread most rapidly by means of underground stems. The underground stems of saw greenbrier bear woody tubers growing singly or in clumps up to 6 inches across. Cat greenbrier has tubers and rhizomes, the latter possessing small prickles between the nodes. Common greenbrier lacks tubers, but has long, slender underground stems. Laurel greenbrier has hard and thickened tubers, but lacks true stolons (*Vines 1960*). These underground stems usually produce new canes annually, and the canes grow quickly.

Nearly all the annual growth of greenbrier stems is completed in a relatively short time. In Texas, common greenbrier started growth in early April, and 90 percent of the growth was complete by 1 May for plants in pine woods and by 20 May for plants in the open. Plants under the pines consistently started growth about 3 to 6 days earlier than those in the open. Mean length of "browse twigs" was 40 percent greater in the open than in the woods—probably representing a real but not statistically significant difference (*Halls and Alcaniz 1972*). There may be some dieback in late summer and fall (*Halls and Alcaniz 1965b*). Clipping and browsing stimulate production of new shoots; up to 60 percent of greenbrier annual growth can be browsed without injury (*Schilling 1938*). Even when all the new monthly growth was removed, common and laurel greenbrier were highly tenacious species in Texas (*Lay 1965a*).

Common and laurel greenbrier sometimes form almost impenetrable spiny thickets. Saw and cat greenbrier are more open and straggling in their growth form, but cat greenbrier often forms dense low tangles in old fields.

USES

Of all vines and shrubs in the Northeast, few if any outrank the greenbriers for wildlife food and cover. The fruit of greenbrier is eaten by at least 38 species of non-game birds (*Martin et al 1951*), such as the catbird, crow, mockingbird, thrasher, robin and other thrushes, white-throated sparrow, phoebe (*Hausman 1931*), and pileated woodpecker (*Hausman 1928*). Common greenbrier and cat greenbrier are important in the winter diet of ruffed grouse, especially in the central and southern Appalachians (*Gilfillan and Bezdek 1944; Nelson et al 1938*) and are taken in the same area by the wild turkey (*Bailey and Riney 1968, Martin et al 1939, Mosby and Handley 1943*). Greenbrier fruits are also eaten by sharp-tailed grouse, prairie chickens, and ring-necked pheasant (*Van Dersal 1938*). Greenbrier seeds may also serve as grit for game birds.

Greenbriers are among the most important deer browse plants, especially in the southern and central Appalachians, where they are utilized throughout the year (*Blair and Halls 1968, Dalke 1941, Goodrum 1961, Lay 1969, Ripley and McClure 1963*). The greenbriers are highly palatable to deer (*Halls et al 1957, Halls et al 1969*), and are exceptionally succulent. Even in fall the twigs contain no more than 32 percent dry matter. And greenbrier browse is relatively high in protein. Deer require a daily protein intake of 13 to 16 percent (dried weight) for growth, and 7 percent for maintenance (*Magruder et al 1957*). The leaves of greenbrier provide sufficient protein for animal growth during the early flush of plant growth in the spring (*Blair and Halls 1968*), and the twigs contain sufficient protein for maintenance in spring (*Blair and Epps 1969*). Protein levels decline steadily throughout the summer, but remain above the amount needed for maintenance until the leaves fall.

In winter the twigs supply, or nearly supply, the needs for maintenance. Laurel greenbrier, since it is an evergreen and leaves are available as browse through the year, adequately supplies maintenance requirements of deer; and the twigs of common greenbrier may also meet maintenance needs during winter. Twigs of common greenbrier collected in Mary-

land contained over 10 percent crude protein in winter (*DeWitt and Derby 1955*), and twigs collected in North Carolina contained over 13 percent crude protein in winter (*Smith et al. 1956*). Twigs of common greenbrier collected in Louisiana, however, contained only 7 percent crude protein in winter (*Blair and Epps 1969*). Like most woody browse species, greenbriers contain adequate amounts of calcium, but are deficient in phosphorus (*Blair and Epps 1969*).

Greenbriers also withstand and respond well to heavy browsing. Up to a point, the more the canes are browsed, the more additional growth they add. Thus, palatability, nutritional quality, and availability make greenbriers important in the management of white-tailed deer in the Northeast as well as in southern United States.

Rabbits also browse the leaves and twigs of greenbriers, especially those of common and cat greenbriers (*Blair 1936 Trippensee 1938*).

For covering tree stumps, trellises, etc., and for an impenetrable fence along property boundaries, horticulturists suggest the common greenbrier as a desirable species (*Everett 1960, Taylor 1948*).

Native North Americans and early pioneers used the roots of some greenbriers as food. They pounded the roots to a pulp, washed them in water, strained this, and allowed the sediments to dry into a fine reddish powder. This powder, after boiling in water, produced a jelly-like pudding. The meal was also used to make bread or cakes, fried in bear grease, and to thicken soups (*Gibbons 1970*). The young shoots of the four greenbriers discussed can be eaten raw as a salad or cooked like asparagus tips. Greenbrier extract was once used as a mild diuretic.

PROPAGATION

Because it is generally considered a nuisance, much more emphasis in the literature is placed on the eradication of greenbrier than on its propagation (*Fernald 1950, Strausbaugh and Core 1952, Taylor 1948*).

A recommended method of propagation is to divide and plant the roots in spring. The soil should be firmed about the roots and kept thoroughly moistened (*Everett 1960*). Canes may not appear from the rootstocks until the second year (*Goodrum 1961*).

Some greenbriers can also be propagated from stem cuttings. In Texas, cuttings about 6 inches long were taken in May when the twigs were actively growing and the leaves were fully expanded, in September when the growth was over and the wood was partially matured, and in January (*Halls and Alcaniz 1965a*). All leaves except two terminals were removed from each stem; the cut ends were dipped in a solution of indolebutyric acid, set upright to a depth of 2 inches in a 3 to 1 mixture of sand and peat, and the cuttings were shaded 30 percent and mist-sprayed regularly. Rooting success was 55 percent for common greenbrier. Saw greenbrier rooted erratically (32 percent), cat greenbrier rooted poorly, and laurel greenbrier did not root at all. Cuttings taken in May generally rooted better than those taken in September, but the latter month is better suited to out-planting in the spring (*Halls and Alcaniz 1965*).

Greenbriers can be propagated from seed, but optimal procedures are unknown. Howard (1915) obtained 51 percent germination of common greenbrier seed in 38 days. The seeds had been cleaned, dried, and stratified outdoors over winter, during which time they were exposed to freezing. Common and saw greenbrier seed in Texas responded well to cleaning and stratification in moist sand at 40°F over winter. Seeds were planted in early spring and lightly covered with soil. Seedlings were ready for transplanting after 1 year in the nursery (*Lowell Halls 1970, personal communication*).

Fruit and seed data supplied by Franz L. Pogge for 52 samples of common greenbrier and 35 samples of cat greenbrier collected at various sites near Morgantown, West Virginia were:

<i>Item</i>	<i>Common greenbrier</i>	<i>Cat greenbrier</i>
Fruit size, inches	1/8-7/16	3/16-7/16
Seeds per fruit:		
Usual number	1-2	1-3
Range	0-4	0-4
Sound seed, average	1.33	1.90
Seed soundness, percent*	51.89	74.94
Fruits per pound, average	1,825	1,550
Sound seed/pound fruit:		
Average	2,425	2,950
Lowest	1,600	2,050
Highest	3,750	3,525
Clean sound seed/pound, average	9,225	9,775

*Excluding one aberrantly low sample for each species.

In current studies (*July 1972*) by the Northeastern Forest Experiment Station, common greenbrier was fairly easy to propagate from seeds, stem cuttings, and root cuttings, but cat greenbrier showed promising results only from tubers collected while dormant (*Franz Pogge, personal communication*).

MANAGEMENT

Greenbrier grows in partial shade, in the open, and on a variety of soils. However, maximum growth of twigs and production of fruit is usually obtained from plants in the open. This suggests that a major management practice should involve release of vines from overhead shade. This would increase fruit production and the quantity and quality of browse.

When canes become too tough or grow out

of the reach of deer, new growth can be stimulated by cutting or disk ing, and by prescribed burning (*Goodrum 1961, Lay 1956*). The underground stems are highly resistant to fire, and new shoots develop quickly (*Lay 1956*). Prescribed burning increased both forage production and protein content of common greenbrier. High-intensity fires produce the highest quality browse. Protein content of browse increased 8 percent after low-intensity fire, and 19 percent after a high-intensity fire (*DeWitt and Derby 1955*).

Eradication or control of greenbrier by cutting is usually ineffective. Individual plants may be eliminated by digging out the roots; but for species as aggressive as greenbrier, this may be impractical. Cat greenbrier has proven rather difficult to control by herbicidal sprays. It is moderately to completely resistant to granular borate TBA applied at the rate of 275 to 400 pounds per acre (*Woestemeyer 1963*), and to fenuron at the rate of 16 pounds per acre (*McCully 1958*). Effective control of greenbrier was obtained by foliar and stem sprays (in water) of 2,4,5-T at 2 pounds acid equivalent per acre (*Elwell 1961*). Common greenbrier was controlled (kill of 95 percent) by spraying with 2,4-D plus 2,4,5-T in oil at 1 to 20 in 1 part oil and 3 parts water applied to the stems and foliage in July (*Niering 1961*). Saw greenbrier was rated susceptible to AMS only, among 9 herbicides (*Dunham 1965*).

HAWTHORNS

Crataegus L.

Also called Cenellier, Haw, Pommettes, Red Haw, Thorn,
Thorn-Apple.

By Ward M. Sharp

*USDI Bureau of Sport Fisheries and Wildlife
Warren, Pa.*

SPECIES

Hawthorns comprise the largest single group of shrubs and small trees in the Middle Atlantic States and Northeastern States and Provinces. Because of the hawthorn's complex nature, the genus is divided into 19 series; and species representing 17 of these series occur in the Northeast. Regional floras or manuals are recommended for identification of the hawthorns. "The Illustrated Flora of the Northeastern United States and Adjacent Canada" (Gleason 1963c), and "The Flora of West Virginia" (Strausbaugh and Core 1953) are particularly helpful because of their illustrations in addition to the keys.

Hawthorns are medium to tall shrubs, 5 to 25 feet in height, with round, dense crowns in some species; crowns of other species are generally cylindrical or conical. Upon close-up inspection, hawthorns are distinguished by the presence of straight or slightly recurving, smooth, hard thorns on the woody branches; and sometimes additional multi-branched thorns on the larger main stems. The presence of stout thorns is a year-round characteristic that distinguishes hawthorns from other shrubs and small trees. The sweet crab apple

[*Malus coronaria* (L.) Mill.] is often mistaken for a hawthorn, but the short thorns in the crab apple arise from the apex of a short, leaf-bearing, spur-like branch.

After mid-August, the small, berry-like fruits of most hawthorns turn reddish to red. Only a few species have yellow or yellowish fruits. The later-ripening species retain their fruits after leaf drop; and, in years of heavy crops, the red fruits impart to the crown a reddish tint that serves as a further distinguishing mark in this season of the year. The red fruits of the deciduous hollies, especially common winterberry [*Ilex verticillata* (L.) A. Gray], also impart a reddish tint in their crowns in autumn.

RANGE

Hawthorns occur throughout the Northeast in pastures, in fence rows on farms, and on idle lands in rural areas. Western sections of Pennsylvania and New York, for example, have a rich hawthorn flora, both in numbers of species and abundance in local areas. Hawthorn abundance is associated with areas where farms were operated for livestock as well as row crops. In areas where row crops

prevailed, hawthorns are uncommon; but, in localities where grazing of livestock was important, hawthorns are common to abundant. In the coastal and piedmont provinces of the region and in the sprawling megalopolis, intensive clean farming and the abundance of eastern redcedar (*Juniperus virginiana* L.) have limited the hawthorns' distribution and abundance.

HABITAT

Hawthorns are well adapted to the climate of the Northeast. Ohio, Pennsylvania, and New York have the greatest array of species; at least 60 percent of all species in North America may occur in these states. Hawthorns are both cold-hardy and drought-hardy except in the flowering period, when the female flower-parts (styles and stigmas) are vulnerable to frost.

The numerous species of hawthorns are adapted to a broad range of soil types, ranging from fertile calcareous soils to acid soils of sandstone origin and low N-P-K content. Hawthorns generally prefer moist or well-drained sites, especially the latter; but sites water-logged in spring support a number of species.

Hawthorns require full sunlight for optimal growth. They are intolerant of shading, and wane and die off when overtopped by a tree canopy. Being tall shrubs, they convert open grassland to a savanna-type community where grasses and forbs are continuous in the ground layer and the tall hawthorn shrubs are scattered throughout the site.

A unit of area populated by hawthorns is defined here as a stand. In Pennsylvania, stands occupied by hawthorns varied in size from 1 to 60 acres, with an average of about 4 acres (Hoover 1961). Past land-use practices determine the development of hawthorn stands. Land grazed by livestock favored hawthorn invasion and development. Cows relished the ripened fruits and disseminated the bony seeds in their dung, which nurtured the hawthorn seedlings and aided their establishment in sodded areas. Grazing by livestock prolongs the life of a hawthorn community.

The hawthorn stand is also a rich site for other shrubs and brambles. Such shrubs as

sweet crab apple, sumacs, dogwoods, juneberries, and blueberries occur in these communities. Old-field species of blackberries (chiefly those of the section *Arguti*) may develop clonal colonies.

Abandoned lands that were previously used for livestock operations are more productive of hawthorns than those used for row crops. But in the absence of grazing, trees usually invade and finally engulf the open land. Common tree invaders are those whose seeds are disseminated by the wind—ash, maple, elm, and pine. Black cherry also invades where seeds are brought in by birds. By repelling browsing animals, hawthorns protect other seedlings that grow up through them, and these invaders eventually shade out the hawthorns and dominate the site. Hawthorns—to their own detriment—are excellent nurse crops for invading trees.

LIFE HISTORY

In Pennsylvania, early flowering species generally begin blooming about May 5, and later flowering species come into full bloom in the first 10 days of June (Hoover 1961). Flowering dates are not identical from year to year because of annual variations in spring temperatures. Because the flowering period of different species extends over a month, late spring frosts would affect only those species in flower at the time of a freeze. In stands with only early-flowering species, for example, an early May frost could eliminate the fruit crop.

The fruits of early-flowering species ripen in late August, while those of late-flowering species ripen after mid-September. Fruits of early-ripening species have soft, pulpy flesh and do not have lasting qualities. Those ripening after mid-September have firm, fleshy fruits. Fruits of some of the latter species, upon falling to the ground and being covered by leaves or grass, remain firm into the following spring.

Seeds of hawthorns are hard, bony nutlets. When fruits are eaten by mammals or birds, only the pulp is digested, and the seeds pass through the alimentary tract. There are exceptions, of course, such as cud-chewing mammals or the larger game birds with gizzards efficient in grinding. Deer pass few seeds, if any, but cattle pass numerous seeds in their dung. In

ruffed grouse, the bony seeds appear to serve as grit, but many are found intact in droppings.

Hawthorns are propagated in nature by seeds. Three factors have been considered important for regeneration: availability of seeds, suitable germination conditions, and survival of seedlings (Hoover 1961). Hawthorn seedlings most commonly establish in grasslands. Best survival is in recently abandoned cow pastures or where grazing is light. Seedlings are unable to establish themselves in full shade.

Hawthorns may grow from a single stem, or two or more may arise from a base. The latter form is often the result of rabbit browsing in the seedling stage or crowding of plants growing side by side. Frequently two or occasionally three plants of different species may arise together, their crown branches forming what appears to be a single shrub. This trait can be confusing in species identification.

Once hawthorns attain about 2 feet in height, the sharp thorns in the compact crown, if hedged from previous browsing, create a barrier to livestock and deer. Cottontails may inflict heavy browsing on seedlings about 6 to 24 inches in height, but rabbits avoid taller plants as a rule.

Since hawthorns are shade-intolerant, they cannot compete with faster-growing trees or tall shrub regeneration that overtops or crowds the sides of the crown. In particular, the spreading, vigorous crowns of sweet crab apple often crowd and weaken hawthorns by shading the sides of their crowns.

INSECTS AND DISEASES

Hawthorns are subject to attack by both insects and diseases. Based on my hawthorn research, those species with thick, leathery leaves are the most resistant, while those with leaves of thin texture are the most vulnerable. Insect infestations are, as a rule, periodic and local. But the troublesome diseases may be an eliminating factor unless the source of infection is eradicated.

Several groups of insects attack hawthorns (Hoover 1961, Johnson et al 1966, Wiegel and Baumhofer 1948). Field studies indicate that the hawthorn lacebug (*Corythucha cydoniae*)

and the wooly aphid (*Eriosoma crataegi*) inflict the most damage over extended areas in Pennsylvania (Hoover 1961). Infestations of lacebugs destroy the chlorophyll by August, leaving the leaves brown and sere. Wooly aphids attack the branches en masse, probe into the cambial layer, and girdle or kill branches along one side.

Defoliating insects known to feed on hawthorn leaves are the tent caterpillar (*Malacosoma americana*) and the fall cankerworm (*Alsophila pometaria*). Outbreaks of the cankerworm are periodic, and only one severe attack on hawthorns was observed in Pennsylvania over a 16-year period. This infestation coincided with a regional irruption occurring across northern Pennsylvania during 1966 to 1968. After two successive years of complete defoliation, hawthorns became weakened and top dieback was prominent.

The hawthorn leaf-aphid (*Anuraphis crataegifoliae*) is a pest (Wiegel and Baumhofer 1948) that seems to cause only minor damage while leaves are succulent. I observed local damage to hawthorn stands by the seventeen-year cicade (*Magicicada septendecim*) in Pennsylvania. The female cicadas damage hawthorns when slitting the branches in the act of laying eggs. Their damage is local because of isolated nature of the outbreaks. The long interval between attacks permits the shrubs to recover.

Two rusts of the genus *Gymnosporangium*, two leafblights (*Fabraea maculata* and *Entomosporium thuemenii*), and fireblight (*Erwinia amylovora*) were reported as causing disease in hawthorns (Johnson et al 1966, Strong 1960). But these blights were not encountered on native species of hawthorns during field work in Pennsylvania (Hoover 1961). The English hawthorn (*Crataegus oxyacantha* L.), its horticultural cultivars, and other exotic species are the principal targets for these blights (Inman 1962, Nichols 1958, Strong 1960).

Two eastern redcedar/hawthorn rusts, (*G. clavipes* and *G. globosum*) parasitize hawthorns. Of all the diseases, the hawthorn rust (*G. clavipes*) is the most destructive, infesting the leaves, fruits, and branches (Hoover 1961). The eastern redcedar is the alternate

host of these rusts. Wherever redcedar occurs, one can expect to find either heavily infested hawthorns, the remains of those that are dying out, or no hawthorns in the area. The cockspur hawthorn (*C. crusgalli* L.) with thick leathery leaves, is one of the few native species whose leaves resist rust. Leaves of the series *Rotundifoliae*, which also are thick, resist damage. But the fruits of the above-mentioned hawthorns are damaged or eliminated by these rusts.

The control of diseases and insects infesting hawthorns requires comment. Attempts to eliminate rusts and leaf blights or hawthorns by use of chemical fungicides have been unrewarding (Chapman and Schneider 1955, Strong 1960, Nichols 1958, Strong and Klomparens 1955, Inman 1962). Applications of fungicide sprays were time-consuming and expensive; and results were temporary. The only permanent solution for the control of hawthorn rusts is to cut the infested redcedars. Several species of junipers are resistant to cedar rust (May 1965). These rust-resistant species should replace the redcedar in future estate and landscape planning. But the problem of values between established stands of hawthorns and redcedars becomes controversial when multiple land ownership is involved.

Leaf blights prove troublesome only among the exotic cultivars such as English hawthorn. Based on my extended field studies of hawthorns in Pennsylvania and New York, the native hawthorns are resistant to leaf and fire blight. Since insect infestations are periodic and local in nature, use of insecticides may prove more harmful to the total hawthorn community than the impact of insect outbreaks.

USES

The fruits of hawthorns are consumed by a number of birds and mammals, including upland gamebirds and songbirds, fur and game animals, and deer and cattle (Chapman 1947b; Martin et al 1951). The occurrence of hawthorn fruits in food studies varies partly because year-to-year yields are inconsistent. There may be good to bumper yields in a particular year, only to be followed by 1 or 2 years of poor yields.

A review of food studies of ruffed grouse in the region reveals that hawthorn fruits are a key item in their fall diet. The fruits are eaten by wild turkeys, beginning with the early-ripening species in August. A recent statewide study of white-tailed deer foods in Ohio showed that the fruits and leaves of hawthorns ranked 14th as a preferred food item (Nixon et al 1970). Cottontails feed on the fallen fruits, and songbirds utilize the fruits adhering to the branches in winter.

The leaves and succulent shoots of hawthorns provide palatable forage for deer and cattle. Heaviest use occurs in May and June, when shoot tips are succulent. Under heavy browsing, plants are hedged to 5 feet above ground. Cottontails browse seedlings under 2 feet in height throughout the year. Hawthorn use by cottontails in Michigan closely approached that of apple which was a highly preferred winter browse (Trippensee 1938). My recent study on the impact of browsing in a savanna community in northwestern Pennsylvania revealed that 85 percent of all hawthorns under 5 feet in height were browsed by deer or by cottontails.

Hawthorn stands serve as special habitat niches for upland wildlife. They are important brood-rearing areas for ruffed grouse and wild turkeys (Sharp 1965), and they form excellent woodcock coverts (Liscinsky 1963). In Ohio, abandoned fields reverting to hawthorns, sweet crab apple, and shrubby dogwoods—all staple deer foods—provide deer with their most productive feeding areas (Nixon et al 1970).

Hawthorns provide nesting sites for several species of birds, including brown thrashers, catbirds, robins, blue jays, and mourning doves (Chapman 1947b). The dense crowns of hawthorns afford protective cover not found in other shrubs or trees. The frail nests of mourning doves are amply anchored against storms. The thorny branches serve as a deterrent to nest predators such as mammals and possibly snakes.

In addition to providing food and cover for wildlife, hawthorns impart aesthetic appeal in the landscape. This large genus of shrubs presents a variety of crown forms, ranging from columnar, flat-topped to roundish outlines

(Hoover 1961, Watts 1946). Hawthorns have been used in landscaping estates, campuses, and other open areas. They contribute to landscape displays through the seasons by their white bloom in spring, their summer foliage, their crimson fruit in autumn, and the gray outlines of their crowns in winter.

Hawthorns are used for screening and for hedges. They have proved valuable in public camping areas for screening between campsites. An outstanding demonstration of this is the Forest Service's Buckaloons Recreation Area in Warren County, Pennsylvania. Hawthorn hedges serve as barriers because their thorns render them formidable. The same trait applies when used for screenings.

PROPAGATION

For those interested in improving wildlife habitat, the best solution to the problem of propagating hawthorns would be the establishment of nurseries consisting of native species. Such nurseries would provide an available source of the most valuable early-, medium- and late-ripening species. The seed source must be certified as to species; otherwise the

fruiting potential and adaptability of the stock may be low.

Commercial nursery stock is expensive, and hawthorn species offered for sale are usually either of exotic or unknown origin. Growing native hawthorns for commercial distribution no doubt entails financial risk on the part of the operator. Will the demand for hawthorns in wildlife plantings be of sufficient volume to warrant the establishment of hawthorn nurseries? Assuming that a nursery is a feasible economic undertaking, one must consider these factors for successful operation. First, a seed source of preferred native species must be located. Second, pretreatment of seeds before planting needs careful consideration. And third, the nursery must be protected against browsing by cottontails.

The fruiting potentialities and other qualities of native hawthorn in Pennsylvania and western New York have been under study during the past 16 years. Because of their annual yield ratings and site adaptability, those species named in table 1 are recommended for propagation in wildlife habitats. Other hawthorns that occur in the aforementioned states, but are not recommended, include 25 species or varieties in 11 series.

Table 1.—Hawthorns recommended for wildlife habitat

Common name	Scientific name ¹	Height, feet	Fruit availability
Washington hawthorn	CORDATAE SERIES <i>C. phaeopyrum</i> (L. f.) Medic	33-39	Fall-winter
Cockspur hawthorn	CRUS-GALLI SERIES <i>C. crus-galli</i> L.	to 33	Fall-winter
Large-seeded hawthorn Roan's hawthorn	TENUIFOLIAE SERIES <i>C. macrosperma</i> Ashe <i>C. m. V. roanensis</i> (Ashe) Palmer	23-26 23-26	Fall-winter Aug.-Sept.
Frosted hawthorn	SILVICOLAE SERIES (THE MIDTHORNS) <i>C. beata</i> Sarg. <i>C. brumalis</i> Ashe <i>C. levigata</i> Sarg. <i>C. populnea</i> Ashe	20-23 20-26 10-13 20-23	Fall-spring do do do
Ontario hawthorn Pennsylvania hawthorn	PRUINOSAE SERIES (THE PRUINOSE THORNS) <i>C. compacta</i> Sarg. <i>C. gattingeri</i> Ashe. <i>C. porteri</i> Britt. <i>C. pruinosa</i> (Wendl.) K. Koch.	10-13 20-23 10-13 23-26	Fall-winter do do do
	COCCINEAE (THE LARGE-LEAVED THORNS) <i>C. anomala</i> Sarg. <i>C. pedicellata</i> Sarg. <i>C. pennsylvanica</i> Ashe	20-23 20-23 29-33	Aug.-Oct. do do

¹According to Ernest J. Palmer in Fernald 1950: 767-801; and Gleason 1963b, v. 2: 338-374.

The Washington hawthorn excels others for its consistent year-to-year fruiting. First, this hawthorn flowers after the first of June in central Pennsylvania when chances of frosts are nil. Second, its towering, columnar habit of growth enables it to compete better than other hawthorns with other woody vegetation. In hawthorn propagation projects, the Washington thorn should represent about a third of the planting stock.

Seed of native hawthorns is the most economical and dependable source of propagating material in wildlife habitats. However, the seeds usually exhibit double dormancy and may need special treatment to stimulate germination during the first spring after ripening. Scarification in sulfuric acid and two-stage stratification (warm-cold) have been recommended (*Flemion 1938*).

It is a standard nursery procedure to collect fruits in the fall and macerate them to remove seeds from the pulp. Cleaned seeds are dried to remove surplus moisture that would cause heating in storage under warm fall temperatures. Refrigerator storage of seeds is a common method of holding seeds, but this practice should be used only as a stop-gap measure before drying or stratification. Seeds should be mixed with sand, the mixture of sand and seeds placed in small wooden boxes lined with $\frac{1}{8}$ -inch hardware cloth, and the boxes stored outdoors for spring planting. But I have had good results by collecting the fruits, storing them outside over winter enclosed in hardware cloth trays (to protect them from rodents, etc.), and planting them into rows in prepared soil in the spring.

Direct-seeding in wildlife habitats and grafting are other methods in hawthorn propagation. Poor results or long waiting periods are likely to result from direct-seeding. Grafting among the species of hawthorns has been successful, but there are drawbacks in matching height-growth forms. The Washington thorn attains a small-tree habit of growth. When this thorn is grafted to one of the low-growing shrubby species, the resulting grafted scion is stunted. The dotted or "gray" hawthorn (*Crataegus punctata* Jacq.) also has a small-tree habit of growth. Since it is the most common and widely distributed hawthorn in the region,

grafting of the Washington thorn to this species is recommended.

Because of the hawthorn rust, propagation of hawthorns should not be attempted in areas where redcedar is abundant. The cockspur thorn is the only common species resistant to leaf rust, but even this species suffers rust damage to its fruits.

MANAGEMENT

This discussion will deal with maintenance of existing hawthorn stands, renovation of invaded stands, establishment of new ones, and the control of disease. Since other native shrubs of value to wildlife are usually associated with the hawthorns in the same sites, preservation and management of these other shrubs must also be considered.

Management of existing stands is a maintenance operation. Since hawthorns and many other shrubs thrive only during a temporary stage in succession, removal of tree invaders is necessary to retard encroachment. Removal consists of cutting invading tree seedlings, saplings, and trees where necessary. In some areas, the sweet crab apples will also need to be thinned to prevent them from crowding the hawthorns.

There are also former hawthorn stands that have been overtopped by sapling and pole-sized trees. Renovating these sites involves cutting the overstory trees. The operation is nearly always worth the effort because there is usually enough suppressed hawthorn regeneration to resurge; furthermore, these sites usually contain a good seed source in the soil.

Establishing new stands either from seed or nursery stock is a long-term project. Before wildlife values are realized, there will be a waiting period of several years, depending on the wildlife species. The project must have a clear objective as well as continuing interest to follow it through. If tree seedlings are also present, they may take over the site while the hawthorns are developing.

Cedar rust can be controlled by cutting the redcedars in areas where they are scarce. But in the Piedmont and Coastal areas, where redcedar is abundant, the job of control is futile. In these areas, the only solution is to go to a rust-resistant species of hawthorn.

HAZELS

AMERICAN HAZEL, *Corylus americana* Walt. Also called American Filbert, Coudrier Hassel, Hazel Brush, Hazelnut, Noisetier, and Wildfilbert.

BEAKED HAZEL, *Corylus cornuta* Marsh., formerly *C. rostrata* Ait. Also called Beaked Filbert, Coudrier, etc. as above.

By Forest W. Stearns

Department of Botany
The University of Wisconsin
Milwaukee

RANGE

Both hazel species are widely distributed in North America (Gleason 1963b). American hazel is found throughout the northeastern region save for the Maritime Provinces (Fernald 1950). It is common to abundant from Maine to Saskatchewan and southward to Georgia, Oklahoma, and Missouri (Rosendahl 1955). Beaked hazel has a more extensive and more northern range than American hazel. It is found from Newfoundland to southern British Columbia and southward to New Jersey and Pennsylvania, westward to Missouri, Ohio, Kansas, Colorado, and Oregon, and occurs in the mountains southward into northern Georgia (Gleason and Cronquist 1963). Beaked hazel is abundant in the northern Lake States, New York, New England, and the southern portions of Ontario, Quebec, and New Brunswick (Rosendahl 1955).

SPECIES

The hazel species are readily identified when in fruit but are difficult to distinguish in the dormant and vegetative condition.

Characteristics useful in identification are listed in table 1 (Hsiung 1951, Wiegand 1909).

Table I.—Hazel identification

American hazel <i>Corylus americana</i>	Beaked hazel <i>Corylus cornuta</i>
Bracts of fruiting involucres broad foliaceous and toothed, open to the nut, downy.	Bracts of fruiting involucres united, much prolonged beyond the nut as a slender foliaceous beak, densely bristly.*
Both twigs and petioles with glandular bristles (<i>hispid pubescent</i>).*	Both twigs and petioles without glands, slightly pubescent.
Buds rounded at ends.	Buds acute.
Leaves rounded-cordate.	Leaves ovate to ovate oblong.
Staminate catkins usually stalked, scales tipped with long reddish point.	Staminate catkins sessile or subsessile, scales with short light-colored tips.

*Smooth (nonglandular and without hairs) forms of both *C. cornuta* and *C. Americana* have been described and are well distributed (Fernald 1950).

Corylus californica (A. DC.) Rose, of the Pacific coast, first described as a variety of *C. cornuta*, differs from it largely in having longer catkins, a shorter beak on the involucrue, a thicker shell on nuts, and greater pubescence on the under side of leaves (*Hsiung 1951*). A variety of beaked hazel from the southern Sierra Nevada Mountains, *Corylus cornuta* var *Tracyi* Jepson, is characterized by leaves with little pubescence and a very short beak on the involucrue (*Jepson 1923*). The only variety described for the northeastern region is *C. cornuta* var. *megaphylla* Marie-Vict. & Rous., which has larger leaves than *C. cornuta* (about 3.5 to 5.5 inches long and 2.5 to 3.5 inches wide) and a very long beak (*Marie Victorin and Rousseau 1940*).

HABITAT

Hazels are found in open woods, thickets, pastures, and clearings (*Rosendahl 1955*). Neither species grows well on poorly drained or organic soils such as mucks or peats nor on fine-textured soils such as clays or silt loams. Coarse sands are also unfavorable. Well aerated and light soils such as loamy sands, sandy loams, and loams support vigorous growth of both species. Hazel stands develop on these soils in association with a variety of forest types, including aspen-birch, northern conifers, and conifer-hardwood mixtures (*Hsiung 1951*).

Hazels are species of the early stages of forest succession. On lighter soils they persist in the mature conifer forest (*Brown 1958, Hsiung 1951, Kittredge 1938*). In New England and adjacent New York, beaked hazel is an important species in the successional sequence from abandoned pasture to mixed pine-hardwood forests. American hazel appears less tolerant of extreme cold, but beaked hazel is less well adapted to higher temperatures. Neither species is adapted to the climate of the Southern States or to the extreme north.

Beaked hazel grows best in slightly acid (pH 5.3 to 6.1), well drained, loamy sands and sandy loams in stands where 30 percent or more of full sunlight is available. A similar pattern holds for American hazel, although field observations indicate that it succeeds in

somewhat drier and sandier soils than does beaked hazel (*Buckman 1964, Hsiung 1951*).

Hazels, by virtue of an extensive and shallow root system, provide considerable competition for tree seedlings; and a dense hazel stand may crowd or shade out other plants. Below a dense hazel stand the light intensity may be only 2 to 7 percent of full sun, and competition for moisture is severe in the upper soil layers. Hazel in Minnesota is often a major competitor for young jack or red pine, and many studies have been made to devise means to eliminate it from young or regenerating stands (*Brown 1958, Buckman 1964*).

LIFE HISTORY

American and beaked hazel reproduce both vegetatively and from seed. After initial establishment, the plant may produce many aerial stems from underground stems or layers. Life-history information is limited and much of the following account is drawn from research (*Hsiung 1951*) at the Cloquet Forest Experiment Station, University of Minnesota. Available information pertains largely to beaked hazel; however, American hazel follows similar patterns.

Production of flowers and seed depend on plant vigor, which is in turn directly affected by forest stand and site conditions and by weather. Weather influences pollination, fertilization, and seed development. For example, a hot, dry spring adversely affects fertilization, and a late spring frost seems particularly effective in killing young ovules (*Hsiung 1951*). Shading also affects production. Many stems growing at low light levels never produce seed. The vigor of individual stems has more influence on flower production than does the vigor of the entire plant (*Hsiung 1951*). Thus, factors such as weather and overstory conditions account for large year-to-year fluctuations in fruit production. American hazel is said to have good seed yields every 2 to 3 years, whereas the interval for beaked hazel may be about 5 years (*U. S. Forest Service 1948*).

The male or staminate flower buds of beaked hazel are initiated early in the growing season and develop slowly until growth ceases in September, at which time the catkins are

evident as elongate buds. The female or pistillate flower buds are initiated later and are somewhat larger than the leaf buds.

Male and female flowers are produced on separate twigs before the leaves appear. Usually male and female buds are present on the same stem. Male catkins, one to three in number, are borne at the ends of the twigs formed in the previous season. Male catkins expand first. Soon afterwards small groups of female flowers develop from scaly buds, which will later form short leafy shoots.

Depending upon location, American hazel flowers in March and April, and the fruit ripens from July to September (*U. S. Forest Service 1948*). In Minnesota the two species flower and their fruit ripens during the same period, April and May and August and September respectively (*Rosendahl 1955*). The mature fruit is a round or ovoid hard-shelled nut surrounded by a husk (involucre) of two leafy bracts, partly or entirely fused.

Male flowers may be produced on stems only 1 year old and female flowers on 2-year-old stems. Flowering increases with stem age, reaching a maximum at 10 to 11 years, after which it diminishes gradually until it ceases at about 18 years. The flowering stems all appear to be of sprout origin, and little is known of the time required to produce flowers from stems of seedling origin in the wild—if indeed it does occur. Male flowers are formed in greater numbers and at an earlier age than female ones. In one sample of 1,224 stems, 53 percent produced male flowers and 29 percent female flowers. Production of both male and female flowers varies greatly even among stems of the same age.

In northeastern Minnesota, the average fresh weight of nuts of beaked hazel was about 1.3 g with a water content of 51 percent (*Hsiung 1951*). Average dry weights were reported (*U. S. Forest Service 1948*) as 0.9 g for American hazel and 0.8 g for beaked hazel (476 and 549 seeds per pound respectively). Weight of the mature nut varies greatly in both species. The range in number of cleaned seed per pound was 197 to 736 for American hazel and 425 to 676 for beaked hazel (*U. S. Forest Service 1948*). Nuts are disseminated primarily by small rodents such as chipmunks

and red squirrels, which often cut the green nuts in early autumn.

Seed production is not well documented, but fluctuates greatly between years. In one area, the number of beaked hazel nuts per acre varied from 13,000 in 1968 to only 44 in 1969. These estimates from a study near Rochester, Alberta, concern stands with 75 percent beaked hazel cover under aspen (*Doris Rusch, personal communication*). American hazel nut production was estimated as 3,000 per acre in Missouri in 1939 (*Dalke 1953*).

Seed production per stem has received only limited study. In most inflorescences only 1, 2, or 3 nuts matured in 60, 33, and 5 percent of the inflorescences respectively (*Hsiung 1951*). The number of inflorescences per stem is highly variable. In good years perhaps 6 to 8 nuts are produced on each fruiting stem (*Hsiung 1951*).

Seedlings are not often abundant in nature because seeds are destroyed by rodents or occasionally by insects or fungi. Some authors have found seedling establishment infrequent and attributed increase in density of hazel to sprouting from underground stems (*Buckman 1964, Hsiung 1951*). In other cases, spread was clearly by seed. A study of hazel in red pine stands revealed many individual clones, each of seedling origin; the older clones were not extensive, at 15 to 20 years of age they ranged in diameter from 2 to 55 inches. Spread by seed is a major factor in invasion of new areas, but requires a good seed source and (temporarily at least) a low rodent population (*Tappeiner 1971*). Dense stands of hazel appear to originate from the establishment of numerous seedlings which in turn produce many aerial stems.

Vegetative spread of hazel clones is slow but accelerates with age; at Cloquet, Minnesota, 6-year-old clones with one or two sprouts had an average diameter of only 0.8 inches, while 38-year-old clones reached 96 inches in diameter and averaged 25 living aerial stems (*Hsiung 1951*). Older clones produced larger and more vigorous sprouts.

Germination of beaked hazel seed is relatively poor. In a Minnesota study, only 26 to 32 percent of the nuts germinated when bur-

ied 1 inch deep in upland forest soil. Those buried in a black spruce-tamarack stand showed 56 percent germination while none germinated in a wet swamp (*Hsiung* 1951). Most other data indicate relatively low germination, between 30 and 60 percent, after cold stratification.

Seedling hazel develops most abundantly under an open forest overstory where nuts, often secreted by rodents, have escaped being eaten. Germination is highest where the nuts were covered sufficiently to prevent drying out during the winter after-ripening period. Buds form in the axils of the cotyledons early in the development of the seedling. These buds usually remain dormant for several years, but may develop immediately into upright shoots if the seedling stem is injured or dies.

As the seedling becomes established, it produces a taproot which penetrates deeply; simultaneously numerous horizontal roots grow into the surface soil. During the first few years, sprout formation is closely related to damage to the main stem; after the plant is well established, the frequency of sprouting increases (*Cheyney* 1928, *Hsiung* 1951). Plants receiving ample light and growing on well-drained soils generally produce a vigorous system of tap and lateral roots. Underground stems are initiated when the seedling is between 7 and 12 years of age. Additional new stems develop vegetatively from aerial stems, underground stems and layers; thus dense thickets of hazel may develop and are perpetuated by sprouting. Over 90 percent of the underground stems and roots are in the top 6 inches of soil (*Hsiung* 1951), and most of these structures are found in the humus layer near the surface of the mineral soil.

Beaked hazel clumps grow slowly at first. Ideally the clump should develop in a radial pattern, but chance and circumstances make this infrequent. In a dense stand one may find as many as 2,250 clones per acre, each producing sprouts (*Tappeiner* 1971). Rapid increase in stem density is often accompanied by an increase in mortality, the average life of an aerial stem in a dense and vigorous stand being relatively short (*Hsiung* 1951).

Sprouting is often stimulated by fire, which may kill the above-ground parts without destroying the underground system (*Buckman*

1964). In Minnesota, a light fire may increase stem density two to four times that of the original unburned stand. One stand 4 years after a spring fire had 40,000 aerial stems per acre, double the number before burning, while after 4 years of spring fires the stem density was 95,000 stems per acre (*Buckman* 1964). Only slow, hot, summer fires, which consume the duff and kill the underground stem systems, serve to eliminate hazel where it is not wanted (*Buckman* 1964). Heavy browsing by deer may stimulate sprouting. Sprout formation is usually followed by rapid growth; vigorous stems may reach heights of over 2 feet in two growing seasons. The average height at 15 to 20 years is about 8 feet. Growth in length declines as the stem ages, and annual growth is often less than 1 inch per year in decadent stems (*Hsiung* 1951).

Growth of beaked and American hazel is favored by ample light and moderate moisture. Neither species will germinate or grow successfully in wet sites nor under dense shade. Hazels grow vigorously in open pastures and brush types or under an overstory of red or jack pine, aspen, or aspen-birch and conifer-hardwood mixtures.

USE BY WILDLIFE

Hazels are important food plants for a variety of wildlife. Stems and twigs are a major component of winter browse for white-tailed deer in portions of the Lake States and presumably elsewhere, and are also commonly eaten by snowshoe hare (*Martin et al* 1951; *Van Dersal* 1938) and moose (*James M. Peek, personal communication*). Some evidence suggests that deer may use beaked hazel heavily, while American hazel is only lightly used. Neither hazel species is highly preferred browse (*Dahlberg and Guettlinger* 1956; *Ross et al* 1970). However, as preferred species have disappeared, hazel has gained importance. At least 30 percent of all stems browsed in northern Wisconsin forests are hazel. Canopy area has been shown to be a good indicator of twig and leaf production (*Peek* 1970).

Winter browsing by deer may be severe, and an entire young hazel thicket may be mowed to snowline. More often, browsing is moderate to light and scattered, because deer prefer new

sprouts and vigorous shoots. In some areas, young hazel stems and leaves may also comprise as much as 30 percent of the summer food of white-tailed deer (*B. E. Kohn, personal communication*). Beaver make considerable use of hazel in some areas in the Northeast, and use by raccoon has been noted (*Martin et al 1951*).

Male catkins provide a rich protein source for ruffed grouse, especially in late winter (*Bump et al 1947; Gullion et al 1962; Korschgen 1966; Martin et al 1951*). Woodcock, sharptail grouse, and other birds make use of buds and catkins (*Martin et al 1951; Van Dersal 1938*) and the nuts are utilized by wild turkey (*Dalke 1953*). Hazel nuts are a major item of food for several mammals. Chipmunks, red fox, and gray squirrels begin their harvest when the nuts are filled but still green (*Hsiung 1951; Martin et al 1951*). These rodents cache the nuts in small piles or bury them individually for later use. Deer may eat the nuts if any remain after the rodent harvest is finished. In Alberta, aspen stands with hazel supported red squirrel (*Tamiasciurus hudsonicus*) densities approximately six times those found in pure aspen stands. Even so, hazel appeared to be a supplementary food, because highest adult red squirrel densities were found in spruce-fir forests. Captive red squirrels on a strictly hazel nut diet consumed an average of 80 nuts per day (*Doris Rusch, personal communication*).

In contrast to other nuts, hazel nuts are especially rich in protein and fats and correspondingly lower in carbohydrates (26.5, 61.4, and 7.2 percent of dry weight respectively). Hazel nuts are relatively much higher in protein and fat than are beechnuts, and beechnuts, in turn, exceed acorns by a large margin (*Wainio and Forbes 1941*).

Hazel clumps provide cover for both woodcock and grouse, especially where the stand is vigorous and well developed (*Korschgen 1966*). Large hazel clumps in fields or fence rows may furnish cover for deer, rabbits, and smaller mammals (*Martin et al 1951*). Dense hazel thickets with closely spaced stems serve ruffed grouse as upland brood range and as drumming habitat (*Gullion et al 1962*).

PROPAGATION

Both beaked and American hazel can be propagated by seed or vegetatively. Commercial use of these species is not frequent although the European filbert (*C. avellana*) is widely propagated. Beaked and American hazel as well as the closely related California hazel have dormant embryos and require stratification; even so, germination is usually low. This is not the case for the European filbert, which gives high germination after 60 days stratification. Propagation by seed in the field requires that seed be protected from rodents. Early autumn sowing is recommended (*Heit 1967c*).

Fruits should be gathered as soon as the edges of the husk begin to turn brown, or they will be lost to squirrels and chipmunks. The green fruits are spread out to dry, and after a few days the husks can be removed by flailing (*U. S. Forest Service 1948*). Avoid drying of the seed. American hazel seed will retain viability for 2 years when stored in a closed container at 41° F, but few beaked hazel seeds remain viable for this long. Stratification in moist sand at cool temperatures (36 to 40°F) serves as satisfactory overwinter storage. If seed is to be sown in the spring, stratification at 41°F for at least 90 days is essential and 120 days are recommended (*Swingle 1939*). Best germination in American hazel was shown in limited tests when seed was stratified, then held at 65°F for 67 days and returned to 41°F for another 30 days (*U. S. Forest Service 1948*).

Seedlings can be grown in the greenhouse where ample soil depth must be provided for development of the taproot. Greenhouse seedlings of beaked hazel averaged about 4 inches tall, bore either 6 or 7 leaves, and developed tap roots averaging 5 inches in length during the first growing season (*Hsiung 1951*). All species can be propagated vegetatively; horticultural varieties are propagated regularly by means of layers, sprouts, cuttings, or grafting (*U. S. Forest Service 1948*). Cuttings are made after the leaves have fallen and are kept until spring in sand beds. Cuttings should be planted just before bud break (*Deam 1932*).

MANAGEMENT

To date hazel management has been concerned chiefly with the elimination of beaked hazel, and especially American hazel, where the shrubs compete with pine seedlings. Techniques used have included mechanical destruction, fire, and herbicides (*Buckman 1964, Klug 1960, Roe and Buchman 1963*). If the underground stems are not destroyed, the treatment will usually result in at least a two-fold increase in the number of aerial stems. Based on this work, management for browse production seems feasible by using techniques shown to encourage sprouting; for example, spring burning at intervals of several years or mowing near ground level at intervals of perhaps 4 to 8 years. Both techniques seem to have merit if more preferred species are scarce.

Establishment of hazel clumps for wildlife seems practical especially if the area in question lacks other appropriate species and if soil and light conditions are suitable. As with most shrub species, reduction of overhead competition will increase stem vigor and stimulate both fruit and vegetative growth.

Management to increase nut production also seems feasible on fertile, well-drained soils in areas where hot, dry spring periods or late spring frosts do not commonly occur. Management for nut production requires that a healthy stand of stems in the 6- to 15-year age class be maintained either in the open or under a light overstory. Hazel has been recommended as a plant for natural hedges and windbreak plantings where it will provide both food and cover to attract birds and small mammals (*Deam 1932, Martin et al 1951*).

HONEYSUCKLES

TATARIAN HONEYSUCKLE, *Lonicera tatarica* L.

JAPANESE HONEYSUCKLE, *Lonicera japonica* Thunb.

AMERICAN FLY HONEYSUCKLE, *Lonicera canadensis* Marsh.

LIMBER HONEYSUCKLE, *Lonicera dioica* L.

HAIRY HONEYSUCKLE, *Lonicera hirsuta* L.

SWAMP FLY HONEYSUCKLE, *Lonicera oblongifolia* (Goldie) Hook

MOUNTAIN FLY HONEYSUCKLE, *Lonicera villosa* (Michx.) Roem. & Schult.

By Lawrence W. Jackson

New York Department of Environmental Conservation
Delmar

SEVEN SPECIES

The seven northeastern honeysuckle species of greatest value to wildlife (table 1), ranked in order of importance, are:

- Tatarian honeysuckle. Widely cultivated and naturalized, it is the most prolific fruit producer.
- Japanese honeysuckle. Widely naturalized, it provides dense escape cover for small mammals and birds, but it is not so dependable a fruit producer.
- American fly honeysuckle. This is the most widely spread native honeysuckle in the Northeast.

- Limber honeysuckle. Its late fruiting provides food for migrant birds. It is widespread, but not as common as American fly honeysuckle.
- Hairy honeysuckle. It provides late fruit for migrant birds, but is discontinuous in range; branches recline on the ground and are not readily available to wildlife in winter.
- Swamp fly honeysuckle. Common in moist areas throughout the region, it is a poor fruit producer.
- Mountain fly honeysuckle. This is strictly a subarctic species, with low fruit production.

Table I.—Honeysuckles: range, growth habit, and fruiting

Common name	Range	Growth habit	Fruit color, time of ripening, and availability
Tatarian honeysuckle	Eurasia. Escaped from cultivation. Ontario to Quebec, south to New England, New Jersey, Pennsylvania, Kentucky, and Iowa.	Erect shrub to 14 feet tall.	Red or yellow. Late June-Aug. to Nov.
Japanese honeysuckle	Asia. Naturalized, particularly near cities; Florida to Texas, north to New Hampshire, Massachusetts, Ohio, Indiana, Missouri and Kansas.	High twining or trailing shrub, half evergreen.	Black. Aug.-Nov. to Mar.
American fly honeysuckle or Canadian fly honeysuckle	Quebec to Saskatchewan, south to New Jersey, Pennsylvania, mountains to North Carolina, Ohio to northeast Iowa.	Straggling shrub 3 to 5 feet tall.	Red. July-Aug. to Sept.
Limber honeysuckle	Southwest Quebec and Maine to Manitoba, south to Georgia and Missouri.	Twining or reclining shrub, 1-2 feet.	Salmon red. July-Oct.
Hairy honeysuckle	Western Quebec and western New England to Saskatchewan, south to Pennsylvania, Ohio, Michigan, Wisconsin, Minnesota, and Nebraska.	Climbing or sprawling vine.	Red. Aug.-Sept. to Oct.
Swamp fly honeysuckle	Manitoba to southeastern Quebec, south to New Brunswick, northern and eastern Maine, northern and western New York, western Pennsylvania, northern Ohio, Michigan, Wisconsin, and Minnesota.	Erect shrub, 2 to 5 feet tall.	Orange-yellow to deep red. July-Aug. to early Sept.
Mountain fly honeysuckle	(Including varieties) Southeastern Manitoba to Hudson Bay to Newfoundland, south to New England, Pennsylvania, Michigan, Wisconsin, and Minnesota.	Depressed or ascending shrub, to 3 feet tall.	Blue. Late May-Aug.

The honeysuckles rank intermediate in value to wildlife. Deer, rabbits, hares, and mice feed on branches and shoots; and birds take advantage of the fruits in season. Japanese honeysuckle is the only one that provides exceptionally good cover for wildlife. The two exotics, Japanese and Tatarian honeysuckle, have been grown in many nurseries; and five of the seven honeysuckles have been widely cultivated. They sprout easily, are handily transplanted, can be grown from cuttings, and establish themselves readily. Most species adapt to a wide variety of soils and are shade-tolerant. Japanese honeysuckle is used for browse and tolerates moderate browsing. It has become a noxious plant in many areas, and control has become necessary. Honeysuckle fruits are available to resident birds during summer months, and to migrants during fall

and winter months. Japanese honeysuckle fruit persists even into March.

TATARIAN HONEYSUCKLE

Habitat

This species, a native of Turkey and southern Russia, was first cultivated in the United States in 1752. It has been planted throughout the eastern United States and southeastern Canada. Little is known about its climatic limitations, but it withstands climates where the temperature drops to -10 to -20°F in winter. This species, like Japanese honeysuckle, has naturalized itself in many places, but is hardier. Its range extends into Canada, beyond the range of Japanese honeysuckle. There is little literature to indicate the extent of spread of this species in southern states.

Tatarian honeysuckle will grow in a variety of soils with pH ranging from acid to alkaline, but the optimum pH range was reported as 6.5 to 8.0 (*Spurway 1941*). It grows on well-drained limestone out-crops (*Lee Chamberlain and Stuart Cameron, personal communication*) in northern New York. No information is available about topographic limitations.

This plant has a wide variety of associates because of its wide distribution. It would be unwise to say that it does best in this or that association because it is still escaping in many areas. In Canada it is found in open maple woods. Biologists have observed it in association with northern white-cedar and heath plants in northern New York; with open hardwoods and in abandoned fields in central and western New York (*Howard Bobseine and Fred Slater, personal communication*), and on the sand plains of Long Island (*John Renkavinsky, personal communication*).

In southern New England, Tatarian honeysuckle grows in several plant associations and on various soils (*Richard Howard, personal communication*). It also occurs in central Maryland on old-field sites and under yellow-poplar or other hardwood stands on good sites (*Silas Little, personal communication*).

Life History

Flowering takes place in June in Canada and New England and in May from New York southward. Twin flowers are born in opposing leaf axils. Flowers are pink to white and about 1.5 to 2 cm long. Fruits (berries) ripen in July and August and are normally red but sometimes yellow.

Of the seven honeysuckles discussed here, Tatarian is the best fruit producer, bearing abundantly in most years. The fruits persist into late summer and early fall and provide food for local and migrating birds. First fruiting occurs at 3 years in nursery-grown plants (*Spinner and Ostrom 1945*).

This is a rapidly growing, bushy shrub that reaches heights of 6 to 14 feet. It does not sprout from the nodes, as Japanese honeysuckle does, and therefore does not spread as rapidly. Seeds are readily eaten by birds and are carried to new locations in this manner. Tatarian honeysuckle withstands moderate

browsing by deer and cattle, and regrowth is rapid. However, after 3 years of heavy browsing, it has been eliminated in areas of high deer concentrations on Long Island (*John Renkavinsky, personal communication*).

Growth is exceedingly good in full sunlight, but maximum plant height in shaded areas is considerably less than that of plants in the open. Tatarian honeysuckle competes well with most other associated plants, particularly in open woods or fields. However, it seldom completely dominates a site as Japanese honeysuckle often does.

Uses

This honeysuckle is the most important one for production and availability of wildlife food. Deer, cottontail rabbits, and mice readily feed on the twigs and bark. The persistent fruits provide food for birds from July through November, so long as migrating flocks do not strip the bushes. Excellent cover is also provided by the bushy growth of this plant (*Gysel and Lemmien 1955*). It provides protection for small mammals, including rabbits and mice, and is ideal nesting cover for small birds.

Tatarian honeysuckle has some value as an erosion-control plant but does not compare with Japanese honeysuckle in this respect. As an ornamental, Tatarian honeysuckle is an excellent general utility species because it tolerates shade and various soil conditions. The plants are also prolific nectar producers and are often planted by bee keepers (*Smith 1946*).

Propagation

Seedlings and seed are available commercially. If seed is to be collected locally, it should be hand-picked or stripped from the shrubs shortly after ripening—to guard against loss to feeding birds. Seed yields were reported as 2 to 12 pounds per 100 pounds of fruit (average 5.5 pounds), and counts of cleaned seed averaged 142,000 per pound (*Swingle 1939, U. S. Forest Service 1948*). Seeds can be cleaned by macerating the fruit in water and floating off the pulp and empty seeds. Dried seeds can be stored in sealed containers at 34 to 38°F for up to 15 years with little loss in viability (*Heit 1967e*).

Seeds can be sown either shortly after ripening or in the spring. For spring sowing, stratification for 60 to 90 days at 40°F has been recommended (*Hartmann and Kester 1968*). After spring sowing, germination is usually complete within 40 to 60 days, or less if the seeds have either been stratified or given a water soak for 24 to 48 hours before sowing. Ordinarily, about 15 percent of the seeds sown will produce usable 1-0 seedlings (*U. S. Forest Service 1948*).

Seeds should be covered with $\frac{1}{8}$ to $\frac{1}{4}$ inch of nursery soil. Though nursery propagation is fairly easy, care must be taken to see that the soil is adequately drained, because the stems rot easily. The young plants grow best if fertilized and irrigated, and may be ready for out-planting as 1-0 to 2-0 stock.

Field planting sites should be well-drained and exposed to full or nearly full sunlight, and should be plowed or at least furrowed before planting. The seedlings will also need at least one cultivation after planting to reduce weed competition.

Though nursery production of Tatarian honeysuckle is almost entirely from seed, it and other honeysuckles can also be propagated from stem cuttings, either hardwood or early-spring. Rooting has been improved by treatment with IAA at 50 mg/l for 24 hours. Sand or sandy soils were recommended as rooting media (*Doran 1957*).

Management

Tatarian honeysuckle is most easily established as 1- or 2-year-old seedlings and will take almost anywhere. But growth on poor soils is much slower than on richer soils, and plants may take several years to attain maximum heights. On poor soils average heights are about 4 feet, on good soils 10 to 12 feet (*Edminster 1950*).

Although little maintenance and care is needed once the plants are established, weeding or release cutting, where needed, may improve growth and fruit production. Leaf lice (aphids) are a potential danger, and Russian authorities have tested insecticides on these pests (*Gunkel 1965, Raukin and Trofimova 1967*). However, little or nothing has been

done about pest control on this continent to date.

Control of this species is seldom necessary. Some experiments on the effects of selected herbicides on Tatarian honeysuckle have been made with varying results (*Birdsell et al 1958*). The insecticides and herbicides used to control Japanese honeysuckle have also been tested on Tatarian honeysuckle.

Miscellany

Spontaneous wild hybrids are not common in the genus *Lonicera*, but several species cross readily when grown together. Since hybrids are fertile, back-crossing is common. This is particularly true of *L. tatarica* (*Greene 1966*). Many of these hybrids are listed by Rehder (1940), Gray's Manual (*Fernald 1950*), and Flora of Bic and the Gaspé Peninsula (*Scoggan 1950*).

JAPANESE HONEYSUCKLE

Habitat

Introduced in 1806, this honeysuckle has naturalized itself over much of the eastern United States. It is particularly common in areas where it has been planted for ornamental purposes and for hedges. Four varieties have been identified, of which *halliana* is the most common.

Japanese honeysuckle adapts readily to a wide variety of climatic conditions. However, it is not hardy in cold climates in the Northeast. The species survives in sand plains in Louisiana (*Brunett 1967*) and oak forests of the Adirondacks (*Greenleaf Chase, personal communication*), as well as in a variety of intergrading climatic situations. It is naturalized in states or portions of states south of the 30°F normal January isotherm and north of the line where only 5 percent of January nights are lower than 32°F. At present it is limited to humid continental climates with warm summers and humid subtropical climates with no dry season. It rarely occurs above 1,200 feet elevation and has not escaped in mountainous sections of New England (*Leatherman 1955*). Also, in Massachusetts and part of New York, the tops freeze back almost every year. Optimum conditions appear

to be met where temperatures are moderate through the winter months and where precipitation is not excessive.

Japanese honeysuckle occurs in sand, sandy loam, loamy sand, and silt loam (*Brunett 1967; Jack McCormick, personal communication*). On Long Island it occurs in the heavier clay soils on glacial moraines (*John Renkavinsky, personal communication*). In Washington, D. C., it grows well on clay soils. The species also occurs throughout northern New York wherever soils are on limestone outcrops (*Greenleaf Chase, personal communication*). However, it is noticeably absent on coarse sands and the poorer peat soils (*Silas Little, personal communication*). Soil pH can range from about 6.0 to 7.5 (*Orville Steward, personal communication*). Best growth is reached on well-drained forest soils (*Leatherman 1955*) and plants spread rapidly where soils are rich in minerals and are within the pH range of 6.1 to 7.9. Topography appears to have little influence on distribution. However, the species has not been planted in many mountain areas and has not been introduced in Canada.

On Long Island, plant associates are black birch, hickories, flowering dogwood, poison ivy, bayberry, and blackberry. Goldenrods and hawkweeds are also common herbaceous associates (*John Renkavinsky and Jack McCormick, personal communications*). In upstate New York, associations are varied, depending on where the plant has been introduced. It is found in oak-pine associations; in white-cedar stands; in white, red, and pitch pine stands; and in stands of mixed hardwoods, particularly where openings have been created. It commonly grows in limestone outcrops in the upstate area in association with the above cover types. However, it is rare in spruce and fir types and coastal pine barrens. Japanese honeysuckle occurs in most plant associations in the Southern and Central States.

Life History

Flowering occurs from June through September in the Northeast (*Richard Howard, personal communication*), and from April through June in the Southeast. Occasionally blossoming takes place in March and July

through October in the southern states (*Wilber Duncan, personal communication*). Flowers are abundant and form in clusters in the leaf axils. The flower is white, tinged with purple fading to pale yellow, and is very fragrant.

Fruits ripen from August to November and are black at maturity. Fruit production is fairly heavy, and seeds are widely dispersed by animals and germinate readily. The fruit is eaten and digested by various birds and small mammals, but seeds pass through the digestive system and are eliminated quickly (*Handley 1945*). No data are available about seed production.

Plants occur as trailing, half-evergreen, woody vines with greatly elongated stems that root sporadically at the nodes. In the Southeast the plant is evergreen, but in the Northeast it is generally deciduous (*Leatherman 1955*). New stems originate from older rooted nodes so that complex layering of stems frequently results (*Keammerer 1967*). The plant is fast-growing and may rapidly dominate a site. However, heavy shade effectively reduces growth and development of mats, even though runners are present (*Little 1967*).

Best growth is attained in full sunlight, and fruiting is most profuse in open stands. Poor success of planted seedlings in Louisiana was partially the result of competing herbaceous vegetation (*Brunett 1967*). However, where Japanese honeysuckle has become established, it spreads rapidly and dominates the site. At the Kalbfleisch Field Research Station on Long Island, the species occupied as much as 80 percent of the main cover once established. In Tennessee, wild plum, black cherry, tree of heaven, red maple, flowering dogwood, and honey locust trees died as a result of competition by Japanese honeysuckle (*Leatherman 1955*). The plant's growth form effectively reduces sunlight and moisture available to other plants, and only the most competitive species can survive in association with Japanese honeysuckle. It may kill trees as large as 6 inch dbh (*Keammerer 1967*).

Uses

Deer, cottontail rabbits, bobwhite quail, ruffed grouse, wild turkeys, and songbirds use this species of honeysuckle, particularly as an

emergency winter food. Both fruit and vegetative growth are eaten by turkey and quail. Nutritive values (including crude protein, fat, nitrogen free extract, crude fiber, and ash) of fruits are equivalent to corn kernels, and growing vegetation is equivalent to timothy hay (Handley 1945). While Japanese honeysuckle is used as emergency food it is seldom a staple in the diet of birds and mammals that use it.

Japanese honeysuckle makes ideal cover for cottontail rabbits, quail, songbirds, cotton rats (*Leatherman 1955*), and wild turkeys (*Rainey 1949*). The evergreen foliage provides winter protection for these species except near northern limits of its range (*Wyman 1955*). The thick tangles of vines also provide excellent nesting sites for many species of small birds (Handley 1945).

It is commonly planted as an ornamental and for forming hedgerows. Cherokee Indians use the stems to make baskets and trays (*Leftwich 1952*).

Propagation

Seedlings are available from some nurseries. Propagation is said to be easy, but I found no practical information in the literature.

Outplanting recommendations given for Tatarian honeysuckle are probably applicable to this species. However, field plantings should be carefully planned with regard to the aggressiveness of Japanese honeysuckle and the risk that it might displace other desirable species.

Management

Management of Japanese honeysuckle has evolved through a series of stages since its introduction to the United States in 1806. The plant was originally introduced as an ornamental and was used in landscaping around buildings. When game management evolved in the mid to late 1930s and early 1940s, game managers were looking for plants that provided abundant food and cover for wildlife. Japanese honeysuckle appeared to provide both of these features. As demand by game managers for planting stock grew, many nurseries increased their capacity for producing

Japanese honeysuckle from seed and cuttings. Even though seedling stock is still being distributed for planting, emphasis has now passed to studying various means of controlling the species where it is established. The Soil Conservation Service has recommended planting in cuts and fills where soil erosion is imminent. In 4 or 5 years the fast-spreading stems form a layering mat that stabilizes the soil.

Japanese honeysuckle establishes readily in most soils. Sand and sandy loam soils are particularly suited to the spreading nature of the plant. Studies at Devon, Pennsylvania, and at Kalbfleisch Field Research Station on Long Island have shown that Japanese honeysuckle will compete favorably with other plant species on old-field sites regardless of whether or not other woody vegetation is controlled. On one study plot at Kalbfleisch, mean cover increased from 21 percent in 1960 to 58 percent in 1967 where woody and other vegetation was controlled. On the undisturbed portion of the plot, mean cover increased from 9 percent in 1960 to 43 percent in 1967. Competition from other woody plants slowed but did not halt the spread of Japanese honeysuckle. Frequency of occurrence was also plotted in these studies because the honeysuckle overlapped and formed matted layers. Frequency on the managed section of the plot increased from 72 percent in 1960 to 88 percent in 1967. On the control section, frequency increased from 58 percent in 1960 to 90 percent in 1967 (*Keamerer 1967; Jack McCormick, personal communication*). In Louisiana, survival of plantings has been poor, but established plants seem to grow well. Studies are being made in Louisiana to determine the feasibility of supplementing winter wheat with Japanese honeysuckle as a winter deer food (*Brunett 1967*). It has been shown that the addition of potassium permanganate to heterauxin solution increases rooting in honeysuckles (*Evenari et al 1946*). However, in southeastern states where Japanese honeysuckle and kudzu-vine (*Pueraria lobata*) are free-growing, establishment of tree seedlings is seriously inhibited because both vines form a dense mat of vegetation (*Brender 1960*).

Once plantings have become established, very little maintenance is needed. The critical

period is in the first year after planting, when the root system is adapting to a new soil. Various fertilizers have been tried, such as 12-12-12, 6-24-24, 0-20-20, ammonia nitrate, and nitrate of soda, on mixed plantings of wheat and honeysuckle in Louisiana. Effectiveness of the various applications was unknown because success of the honeysuckle plantings was poor (Brunett 1967).

Because of its ability to spread rapidly, to compete aggressively with other species, and its tenacity in dominating a site, control of Japanese honeysuckle has become a necessity. Several nonchemical approaches to control have been tried, including burning, isolation by grazing, repeated cutting, cultivation, and shading. Grazing, burning, and repeated cutting reduce the plant temporarily. However, some root crowns survive even the most intensive measures and soon establish full cover by rapid regrowth of sprouts (Little 1967b). Under a closed canopy, the plants are eventually shaded out (Leatherman 1955).

Use of herbicides has been by far the most effective control measure. Since 1950 a variety of herbicides have been tried, with varying results. Amine salt of 2,4-D, applied without addition of a spreader, caused 90 to 100 percent killing of Japanese honeysuckle growing in sparse stands in shaded areas. A kill of 50 percent or more occurred in dense stands 8 to 10 years old and exposed to full sunlight. The influence of light and time of year of spraying were more important than herbicide concentration. A respraying on 3 July was more effective than a single respray applied on other dates (Hitchcock and Zimmerman 1949).

Comparative studies of the effect of ammonium sulfamate, borax, and 2,4-D on poison ivy and honeysuckle were made in the National Capitol Parks, Washington, D. C. Treatments of borax and 2,4-D applied two or three times during the growing season effectively controlled honeysuckle under some conditions (Webster 1950).

Plant toxicity of insecticides, in mist concentrates, has been tested on a variety of shrubs. Five percent solutions of the insecticides were applied directly to the plant leaves. Most phytotoxic were malathion, lindane, heptachlor, chlordane, and DMC. Least phyto-

toxic were aldrin, isodrin, dieldrin, DDT, ovo-tran, chlorobenzilate, and compound 923. The genus *Lonicera* was the most susceptible in all cases (Clower and Matthysse 1955).

At Clemson University Research Center, 2,4-D and 2,4,5-T effectively controlled honeysuckle in yellow-poplar stands on bottom lands. In the southeastern United States, very rapid reinvasion of honeysuckle on bottom-land sites was found; honeysuckle seedlings grew so rapidly that in 1 year the vines reached the top of a yellow-poplar 14 feet tall (Bruner 1967, 1968). Such rapid regrowth did not occur in Maryland, and various conditioning treatments permit the dominance of yellow-poplar seedlings over Japanese honeysuckle under most northeastern conditions (Little 1968).

To be completely effective, the controlling herbicide must destroy the honeysuckle plant. Various herbicides have been used to release pine or hardwood seedlings from competition of Japanese honeysuckle or to eliminate honeysuckle in areas being prepared for tree regeneration. Considering both the degree of honeysuckle control and the amount of damage to desired trees, 2,4-D emulsifiable acid, applied in late fall for release of hardwoods and in late summer or early fall for release of pines, is effective. A mixture of 2,4-D and picolinic acid applied during spring or early summer has been recommended as a conditioning treatment to prepare an area for new tree regeneration (Little 1968).

Present control methods are expensive, and attempts to develop more economical methods are needed (Brender 1960). Future research will probably emphasize biological control methods.

AMERICAN FLY HONEYSUCKLE

Habitat

As indicated by its range, this species is more cold-hardy than Japanese honeysuckle, but about equivalent to Tatarian honeysuckle. Fly honeysuckle thrives in cold climates, but southward of Pennsylvania it occurs only in the mountains.

American fly honeysuckle occupies both

acid and alkaline soils throughout its range, but does particularly well in acid soils in the southern portion (*Wilber Duncan, personal communication*). In the north it typically occupies dry, rocky woods, particularly in Ontario and Quebec (*Dorothy Swales, personal communication*). In upstate New York and New England, this honeysuckle occurs in a wide range of soils formed from granite and calcareous sandstones. On the north shore of Long Island, American fly honeysuckle is found on glacial outwash plains (*John Renkavinsky and Anthony Taormina, personal communications*). It does not thrive in dry, sandy soils.

American fly honeysuckle grows best in rich, damp woods where soils include an accumulation of organic matter, and may be most abundant in mountain areas where the soil has not been disturbed. The species can be found under northern hardwood and mixed hardwood/conifer overstories in New York and New England (*Greenleaf Chase, personal communication*). However, in the southern portion of its range, American fly honeysuckle occurs more frequently in moist rich soils under hardwoods, simply because hardwood stands are more abundant than conifer or mixed stands.

Common plant associates in upstate New York, New England, Ontario, and Quebec are serviceberry, witch-hazel, beaked hazel, viburnums, gooseberry, yew, red maple, sugar maple, striped maple, mountain maple, eastern hemlock, red spruce, balsam fir, aspen, birches, spirea, and sedges. On Long Island and the New Jersey coast, associates are serviceberry, flowering dogwood, and various sedges (*John Renkavinsky, personal communication*).

Life History

Flowering occurs primarily in April and May throughout the range. American fly honeysuckle is conspicuous as one of the earliest shrubs to leaf and flower. Flowers are scattered in leaf axils but occur in pairs. Blossoms are funnel-shaped, about 2 cm long, and yellowish-green to straw-colored. Fruits are red, fleshy, several-seeded berries that ripen in July and August. This species is not a prolific

producer of fruit. Wherever it grows in shade, fruit production is sharply reduced.

Regeneration of plants is by shoots from a spreading root system and from seeds eaten and transported by birds and small mammals. Seeds are scarified as they pass through the digestive tract of the animal or bird. Undoubtedly this species spreads more commonly by shoots from underground root systems than from seeds.

Growth form is erect, and the shrubs are 3 to 5 feet tall at maturity. Growth is more rapid in open sunlight than in shaded woods (*Richard Howard, personal communication*). However, American fly honeysuckle is shade-tolerant and persists even under thick cover. It competes favorably with its plant associates under most conditions but is not an aggressive plant like Japanese honeysuckle and will not dominate a site.

Uses

Moose, deer, rabbits, and hares make ready use of twigs and foliage of this plant. It is a preferred food of deer, particularly during winter, but rarely is their staple food because it does not occur as abundantly as the maples, viburnums, and other staples. Furthermore, it often is not available to browsing mammals in the northern portion of its range because of deep snow during winter. Ruffed grouse, quail, and small birds eat the fruits as they ripen in August (*Greenleaf Chase and John Renkavinsky, personal communications*). However, the fruit is not persistent and will not provide food for birds during late fall or winter (*Ralph H. Smith, personal communication*). American fly honeysuckle offers little value as a cover species. The open growth form provides little protection and the early fruit drop prevents small mammals and birds from using it in the fall. The species is rarely planted as an ornamental.

Propagation

American fly honeysuckle has been cultivated since 1641, but plants or seeds are not known to be available commercially. For local collection of seed, fruit should be hand-picked or stripped from the branches as soon after

ripening as possible. Since most *Lonicera* species hybridize, it is better to collect seed from isolated shrubs that have desirable characteristics. Seed is extracted by macerating fruit in water and allowing empty seeds and pulp to float away. After a short drying period, seeds are ready for storage (*U. S. Forest Service 1948*), preferably in sealed containers kept at 34 to 38°F (*Heit 1967e*).

Most of the natural germination of honeysuckles takes place in the spring after seed dispersal, but some species, notably Tatarian, may germinate in the fall, shortly after ripening. I found no specific recommendations for propagating American fly honeysuckle. However, general recommendations for the genus are that seed of lots showing embryo dormancy should be sown broadcast or in drills in the fall, or stratified before early spring sowing. Species of known impermeable seed coats should be sown as soon as possible after collection to insure germination the next spring. Nondormant seeds can be sown in the spring without pretreatment. This may be the best recommendation for American fly honeysuckle and limber honeysuckle, because outdoor stratification of these species for 83 days gave no practical benefits (*U. S. Forest Service 1948*).

Management

Since both food and cover values of the plant are low, it has seldom been considered in habitat-management plans. When established, the plant maintains itself well. Consequently no actual maintenance has been practiced by game managers on this species of honeysuckle, and it is unlikely that it ever will receive serious management consideration.

Honeysuckles are used as browse indicators for deer in winter concentration areas along with more staple species such as maples, viburnums, and beaked hazel.

LIMBER HONEYSUCKLE

Habitat

This is a versatile honeysuckle that adapts to a variety of climates throughout its range. It survives temperature extremes of 5 to 10°F. in the southern portion of its range and -35 to -50°F in the north.

Limber honeysuckle is found growing on a wide variety of soils. These include loam, sandy-loam, gray and red forest soils, and glacial till, and outwash plains. It is also present on calcareous soils and on well-drained quartzitic sandstone where sunlight is abundant (*Greenleaf Chase and Dorothy Swales, personal communications*). Topographic limits are not known, but field observations indicate that limber honeysuckle grows best on sandy, well-drained plateaus above 2,000 feet in elevation.

In general this species is found in association with trees and shrubs of open, sandy plains and dry, well-drained woods (*Greenleaf Chase and Wilber Duncan, personal communications*). In northern New York it does well in association with blueberry and white pine at Ray Brook in Essex County and on jack pine plains in Clinton County (*Greenleaf Chase, personal communication*).

Life History

Flowering occurs in late May in Canada and early April in the southern portion of the region (*Dorothy Swales and Wilbur Duncan, personal communications*). Flowers appear in one to three whorls at the end of leafy branches, and are greenish-yellow or straw-colored to brick red or purple. The fruits form in clusters of 3- to 4-seeded berries, which are salmon-red when they ripen, usually in August. This fruit sets well and is available to wildlife much longer than the berries of American fly honeysuckle. The seeds are enclosed by the fleshy fruit and are eaten with the fruit by wildlife. However, seeds are passed readily from the digestive tract of animals and birds.

Limber honeysuckle is a low-growing shrub, 1 to 2 feet tall, with decumbent branches that commonly twine around adjacent plants. Growth is fairly rapid on sandy soils. Regeneration occurs mostly through new shoots from plant roots. Seeds are spread by birds (chiefly song birds) and small mammals. Seed coats are scarified in passing through the digestive tracts of birds and mammals, and this may increase subsequent germination. However, this species is rarely abundant.

Growth and fruit production are best where limber honeysuckle is exposed to sunlight. On

sandy plains in association with blueberries it maintains itself but seldom replaces or hinders growth of the blueberries.

Uses

Deer, hares, and rabbits utilize the twigs of this plant. However, because of its scattered presence and low growth form, it is not used to any great extent by these species. The fruits are eaten by grouse, song birds, and small mammals, particularly rodents. Since the fruits set well, they provide food during late summer and early fall. However, this source of food cannot be considered important. Negligible cover is provided by limber honeysuckle because the plants usually are scattered and leaves drop early in the fall.

Propagation

Limber honeysuckle has been cultivated since 1636, but seeds or planting stock are seldom, if ever, available from state or commercial nurseries. I found little specific information about limber honeysuckle except that it and American fly honeysuckle may have little or no seed dormancy. More details are given in the discussion of American fly honeysuckle above.

Management

This species plays an unique role in a balanced ecosystem, but in itself cannot be considered important in wildlife management. Limber honeysuckle has established itself on blueberry barrens, in openings in the forest, and along roadsides. Apparently, loose soil, such as is found on sandy barrens and on disturbed road right-of-ways, favors germination of seeds. The plant usually maintains itself as long as other plants do not completely shade it out in the process of plant succession. Burning of blueberry barrens may or may not be of advantage in maintaining stands of limber honeysuckle. No management practice of this nature has been documented.

HAIRY HONEYSUCKLE

Habitat

The range of hairy honeysuckle is discontinuous. It is found in acid bogs and coniferous forests in the north; in moist areas of the Appalachian Mountains, including the Alleghenies, Catskills, and Adirondacks; and generally in cool, moist sites elsewhere throughout its range. In the southern portion of its range it is generally found at higher elevations. However, in the northern latitude of Quebec and Ontario it is found near sea level (*Dorothy Swales, personal communication*). Extremely cold temperatures and long periods of dormancy beneath deep snow apparently do not limit this species. It grows under winter temperature extremes of -5 to 10°F in the southern portion of its range and of -20 to -35°F in the north. It does not grow in areas of low rainfall or where precipitation is quickly dissipated.

Hairy honeysuckle usually grows in poorly drained acid soils underlain with clay, where plants are surrounded by moisture through most of the year.

Plant associates of hairy honeysuckle are red and black spruce, tamarack, white pine, balsam fir, black cherry, serviceberry, red maple, beaked hazel, heath plants, and viburnums. It has been observed growing in the shade of a northern white-cedar swamp (*Ralph Smith, personal communication*). Alders and willows may also grow in close association.

Life History

Flowering occurs in June and July, later in northern latitudes. The floral tube is 2 to 2.5 cm long, orange or yellow, and hairy. The fruit is a berry, which turns red when it ripens in mid to late August and early September.

This species is a sprawling and climbing shrub with winding, twisting branches that may twine around other plants nearby. This growth habit gives the leaves of the hairy honeysuckle an advantage in reaching for sunlight. Regeneration is by shoots springing up from the spreading roots and from seed dispersed by birds and small mammals. The

SWAMP FLY HONEYSUCKLE

Habitat

This species is usually restricted to wet woodlands, bogs, swampy thickets, and roadsides in lowlands (*Fernald 1950*). It apparently grows best in moist acid soils and in full sunlight (*Van Dersal 1938*), but detailed habitat information is lacking. The most common associates probably are heath plants, viburnums, dogwoods, and wet-site conifers.

Uses

Moose, deer, and snowshoe hares eat the twigs and foliage. However, because of the low growth form and the tendency to be covered by snow in winter months, use by deer and moose is generally slight. By contrast, hares live in close association with hairy honeysuckle; and use in winter may be moderate to heavy along edges of conifer swamps. Some use may be made of fruits by birds and small mammals, but this has not been documented. Hairy honeysuckle is too spreading in growth form and too scattered in its occurrence to provide good protective cover.

Propagation

This species has been cultivated since 1825, but is not available commercially. Some information given about propagation of American fly honeysuckle applies to this plant. Seed lots of hairy honeysuckle have shown both seed coat and embryo dormancy. Optimum seed treatment is unknown, but fair germination was obtained following warm/cold stratification in sand or peat for 60 days at 68 to 86°F (daily alternation) followed by 60 days at 41°F (*U. S. Forest Service 1948*).

Management

The species has established itself on a variety of soils in the Northeast, particularly on sandy plains and stream banks, and may have some limited potential in management for snowshoe hares. Stock from nurseries have been used for ornamental plantings, but plantings for wildlife have been negligible. The plants thrive and grow well when established in their preferred habitat, and would seldom require either maintenance or control.

Life History

Flowering occurs from late in May to July, and the fruit ripens from late July to early September. Ripened berries usually are deep red in color and do not persist on the plants. Fruit production is light compared to that of Tatarian honeysuckle.

The plant is a small erect shrub, 2 to 5 feet tall. Regeneration is from root suckers and seeds dispersed by birds. This species commonly persists on wet sites but usually is not prolific.

Uses by Wildlife

Deer, hares, and cottontail rabbits browse swamp fly honeysuckle but the extent of this use and possible uses by birds and small mammals have not been documented. Due to its growth form, this species has only minor cover value for wildlife.

Propagation

Stock is not available commercially, but some of the information given for American fly honeysuckle applies. An exception is that seeds of this species apparently have both seed coat and embryo dormancy. Dual stratification has been used: 60 days at 68 to 86°F (or 50 to 77°F), followed by 90 days at 41°F. This pretreatment gave fair germination results in one sample (*U. S. Forest Service 1948*), but probably is not an optimal treatment. The number of cleaned seed per pound was 238,000 in one sample (*U. S. Forest Service 1948*).

Management

No management experience with this species has been documented. Its wildlife values probably do not justify specific management practices other than those that apply to associated species such as the heath plants, viburnums, dogwoods and willows.

MOUNTAIN FLY HONEYSUCKLE

Habitat

This species, including four varieties, is basically a subarctic plant that prefers cool, moist summer conditions and withstands winter temperature to -50°F and long dormancy periods beneath snow (*Dorothy Swales, personal communication*). Optimum conditions have not been determined, but none of the varieties ranges southward in the mountains beyond northeastern Pennsylvania.

Mountain fly honeysuckle occurs mostly on peaty acid soils in or near bogs or rocky barrens, but also grows on limestone-derived sandy and other soils (*Van Dersal 1938*). The sites are moist to well-drained and usually in full sunlight. Near the southern limits of the range, the plant usually occurs at high elevations near mountain ponds or bogs; it has been noted growing at 5,000 feet in elevation, above the timber line on Mt. Marcy in New York (*Ralph Smith, personal communication*). Farther north, in Canada, it grows at or near sea level in the taiga and along edges of the tundra.

This species almost always grows in association with heath plants, red or black spruce, tamarack, and balsam fir (*Greenleaf Chase, personal communication*).

Life History

Flowering occurs from late April to July, and the fruit—a blue berry—may ripen from early summer to August. Fruit production is

relatively scanty, but little or nothing has been documented about fruit productivity, seed characteristics, minimum bearing age, etc.

Mountain fly honeysuckle grows close to the ground, and seldom is over 1 to 2 feet tall. Its occurrence is usually scattered; new plants probably arise from seeds dispersed by small birds and microtine rodents. Root suckering probably accounts for most of the spread of established plants. Best growth is attained in full sunlight, but abundance is limited where evergreen heath plants dominate the site and shade the honeysuckle. This species is generally free from insect and disease attack (*Van Dersal 1938*).

Uses

Snowshoe hares, deer, and moose browse this species, but the low-growing plants are generally unavailable beneath the snow during winter. However, deer browse the plants heavily in the late winter and spring as the snow melts (*Ralph Smith, personal communication*). Plants will persist well even under heavy browsing by deer and hare. The fruits are edible for humans, and small rodents and song birds make use of them. Potential food value to wildlife is low because of the plant's scattered occurrence, unavailability during winter, and low fruit production. This species has little cover value except for small rodents.

Propagation

No specific information is available.

Management

Since this species grows in scattered remote areas and has fairly low value for wildlife, there is little justification for species management.

Established plants in the wild are self-maintaining. No management is being practiced on this species. Control is not necessary.

EASTERN HOPHORNBEAM

Ostrya virginiana (Mill.) K. Koch

Also called American Hophornbeam, Bois de Fer, Deerwood, Eastern Ironwood, Hornbeam, Ironwood, Leverwood, and Rough-Barked Ironwood.

By Tom S. Hamilton, Jr.

*University of Massachusetts
Amherst*

RANGE

Eastern hophornbeam reaches its northward limits within the Northeast, but extends far to the west and south. The range is Nova Scotia to Maine, southern Quebec and Ontario, northern Michigan and Minnesota, southern Manitoba, and eastern North Dakota, south to eastern Texas, northern Mexico, and northern Florida (Little 1953).

HABITAT

This species grows under most of the climatic conditions that occur in the Northeast, except in the coldest areas. Optimum conditions for growth have not been determined, but the largest specimens are in southern Arkansas and eastern Texas.

Annual precipitation in the range of hophornbeam varies from about 20 inches in the west to about 60 inches in the south, with an average of around 45 inches. In the north, precipitation is fairly well distributed throughout the year, while in the south the rainfall averages about 50 inches a year, with an average of 37 inches from March to September (Shel-

ford 1963). Temperatures in the range of this species vary from an average in January of 0°F (northern Nebraska) to 60°F (northern Florida), and an average in July of 65°F (north) to 80°F (south) (U. S. Forest Service 1965). This species can be found at elevations of sea level to about 5,200 feet in the southern Appalachians.

Hophornbeam grows best on moist but well-drained, fairly fertile to rich soils, particularly in limestone regions. In New York and elsewhere, hophornbeam is a common invader of moister sites in old fields and often precedes or accompanies white pine (Bump 1950, Hosely 1938). However, the species is adaptable and occurs as a scattered understory plant in most of the forest types found in the Northeast (U. S. Forest Service 1965). Though it prefers moist, rich soils, hophornbeam grows in a wide variety of soil and moisture conditions. Associated understory species vary among forest types, but may include serviceberry, American hornbeam, witch-hazel, maple-leaf viburnum, striped maple, red maple, pinxterbloom azalea, and blueberries (Bump 1950, Kurmis 1970).

LIFE HISTORY

Hophornbeam flowers in April to June in the Northeast. Flowers of both sexes occur on the same plant, but they are separated by being in different catkins. The male-flower catkins are about $\frac{1}{2}$ inch long, slender, pendulous, and naked during their first season and winter, often in twos or threes at the ends of the twigs, and scattered in the crown. They are 2 to $2\frac{1}{2}$ inches long and drooping when in bloom. The female-flower catkins are about $\frac{1}{4}$ inch long, upright, slender, in small open clusters at the ends of small leafy branches. Fertilization is by wind-borne pollen.

The fruit is a ribbed, spindle-shaped nutlet about $\frac{1}{4}$ inch long. It is enclosed by a bladder-like sac which is part of a slender-stalked, pendulous, hoplike cluster, about $2\frac{1}{2}$ inches long. Fruits ripen in August-October and occasionally persist into the winter. The hops are bright green in early autumn and light gray to greenish brown when ripe.

The hops dry and gradually fall apart soon after ripening, and are dispersed largely by the wind, but occasionally by birds (*U. S. Forest Service 1948*). Seed production per plant varies from year to year. The plants do not produce seed in quantity until about 25 years old.

Reproduction in the wild is mostly by seeds, which germinate in the first spring after seed fall. The mature plants are usually round-headed trees, to 20 to 30 feet in height, with a trunk 12 inches or less in diameter. The largest hophornbeams are in Arkansas and Texas; some are 60 to 70 feet tall, with trunks 18 to 24 inches in diameter.

This species is able to grow in dense shade and is usually an understory tree. It is a slow grower and not aggressive, and its ability to grow in shade makes it valuable for underplanting or retention in the shade of oaks and other large trees. Hophornbeam is fairly free from serious insect and disease pests (*Hepting 1971*). It is also highly resistant to damage by wind, snow, and ice, and the heartwood is durable in contact with the soil (*Hepting 1971*).

USE BY WILDLIFE

Hophornbeam is an important food of ruffed grouse, particularly in New York, Pennsylvania, and Wisconsin, but may be less important in New England and south of Pennsylvania. In winter, the buds and catkins of hophornbeam rank as food with those of aspen and birches, and with apple buds. Among various winter food habit studies of grouse, hophornbeam comprised 0 to 14.7 percent (average 3.9) by volume. The fruits are secondary foods in the fall, and the buds are primary foods in December to May (*Edminster 1947*).

Sharp-tailed grouse feed on hophornbeam in Michigan and elsewhere, and use it as a staple food in Quebec (*Van Dersal 1938*). Other species that eat hophornbeam fruit, buds, catkins, or twigs, mostly to a lesser degree than the grouse, include: ptarmigan, bobwhite, red, gray, and fox squirrel, deermouse, deer, cottontail, ring-necked pheasant, purple finch, rose-breasted grosbeak, and downy woodpecker (*Hosely 1938, Martin et al 1951*).

As food of cottontails, bark of hophornbeam ranked above the middle among 24 species of woody plants. Analysis of the bark, in percent, showed moisture 6.2, ash 5.2, crude protein 6.1, crude fiber 20.1, fat 3.7, and other non-determined extracts 58.7 (*Dalke and Sime 1941*).

Hophornbeam also provides some nesting or escape cover for small birds and mammals (*U. S. Forest Service 1948*).

PROPAGATION

Nursery-grown plants from 5 to 12 feet tall and $1\frac{1}{4}$ inch caliper were available recently from 10 nurseries in the United States, one in Canada, and one in England. Collected stock was available from three other nurseries, in sizes 5 to 10 feet tall and $1\frac{1}{2}$ to 4 inch caliper. Seed was available from at least one source in the United States (*LMIS 1966, Mattoon 1958*).

The fruits can be hand-picked in late summer or fall when they are pale greenish-brown but before they are dry enough to shatter. When fully ripe, the hops are greenish-brown to light gray. After drying, the hops can be

beaten or rubbed and the seed can be separated from the chaff by fanning. One bushel of fruit will yield approximately 2 pounds of seed; 100 pounds of fruit yields about 21 pounds of seed. Cleaned seeds average about 30,000 per pound. If necessary, cleaned and dried seed apparently can be stored at low temperatures for some time, but optimum storage conditions and viability have not been reported (*Swingle 1939, U. S. Forest Service 1948*).

Either fall or spring sowing of seed in well-prepared nursery beds is feasible. Fall sowing should be done in drills soon after the seed has been collected, preferably in early September. In one case seed was collected when slightly green in August and sown immediately. Germination was 100 percent the following spring (*Titus 1940*). Fall-sown beds should be mulched with burlap, straw, or similar material until germination begins in the spring. Then mulch should be removed.

To prepare for spring sowing, seed can be stored over winter in moist sand or peat at 41°F. However, a warm-plus-cold treatment may be better. Recommended treatments are 60 days at 68 to 86°F then 140 days at 41°, or 6½ months at 50 to 77° then 90 days at 41°. Limited tests of such treatments yielded germinative capacities of 27 and 65 percent (two tests) and potential germinations of 85 to 90 percent (*Sandahl 1941, U. S. Forest Service 1948*).

In the nursery, the stored seed should be sown as soon as the soil can be worked. The seedbed should have well-drained, loamy, mineral soil. Plant the seed ¼ inch deep in rows in open, sunny beds, firm the soil over the seed, mulch, and keep moist. Germination should take place during the same spring, but if it is irregular, cover the beds with leaf mold to prevent excessive drying during the summer. In the second year after germination, remove the seedlings from the bed and line them out in open nursery rows (*U. S. Forest Service 1948*).

Direct field planting of seed is not recommended, but the best natural seedbed would

be a moist, well-drained, loamy, mineral soil partially protected by vegetative cover.

Nursery-grown stock transplants fairly well, but it is important that some soil from the growing beds be moved with the plants to insure the symbiotic root-fungus association (*Shelford 1963*).

MANAGEMENT

This species may be most valuable in woodlands managed at least partly for grouse and the other wildlife named above. If hophornbeam is present, it should be retained except where it competes with plants having greater wildlife value. Being a highly shade-tolerant understory tree, hophornbeam is usually not a serious competitor with timber species (*Edminster 1947*). Light thinning of overstory trees may increase fruit production, but complete overstory removal would seldom be warranted.

Natural establishment of hophornbeam usually is from seed distributed by wind or birds. However, to establish the plant for wildlife use, the preferred method is to plant 2-foot high or taller stock in masses or groups in forest openings, woodland borders, or old fields. Since hophornbeam is disease-resistant and shade-tolerant, little or no maintenance would be needed.

Supplementing its wildlife value, hophornbeam merits consideration as an attractive, small-to-medium size, ornamental tree. The crown is usually round-headed, and the foliage and light-green-to-brown fruit are handsome in the fall.

Hophornbeam would seldom need to be controlled. It is moderately susceptible to herbicides such as D-T and 2,4,5-T applied as foliage sprays (*Egler 1949, Wendel 1966*).

MISCELLANY

Hophornbeam wood has home uses and some commercial value. The wood is strong, hard, tough, and durable, and is useful for fence posts or levers, wedges, tool handles, mallets, and similar small articles (*Grimm 1966*).

AMERICAN HORNBEAM

Carpinus caroliniana Walt.

Also called Blue Beech, Ironwood, Musclewood, and Water Beech.

By Robert W. Donohoe

Ohio Department of Natural Resources
New Marshfield

RANGE

This species occurs throughout the Northeast and southward to northern Florida, westward to eastern Texas, and northward to Minnesota and Ontario. It is most abundant and grows largest on the western slopes of the southern Allegheny Mountains and in southern Arkansas and east Texas (Sargent 1922).

HABITAT

American hornbeam is adapted to a wide variety of climates within the region. It occurs mainly on rich, moist soils in bottomlands, coves, and lower protected slopes and is common along the borders of streams and swamps (Sargent 1922, U. S. Forest Service 1948).

Three distinct forest types are recognized in the Region: (1) mixed mesophytic; (2) oak-chestnut; and (3) hemlock - white pine - northern hardwoods (Braun 1950).

The mixed mesophytic climax is a community in which the dominant canopy trees are beech, yellow-poplar, basswood, sugar maple, chestnut, sweet buckeye, red oak, white oak, and hemlock. To this list must be added the lower trees, which seldom or never attain canopy position. These include American horn-

beam, dogwood, the magnolias, striped maple, redbud, hophornbeam, holly, and service-berry (Braun 1950).

Chestnut oak, black oak, and red oak communities, or combinations of these, represent the former oak-chestnut forest type. The red oak community is the most mesophytic. Canopy trees associated with these communities include yellow-poplar, hickories, beech, sugar maple, white ash, and black cherry. Species of secondary importance in the understory are American hornbeam, flowering dogwood, sassafras, and hophornbeam (Braun 1950).

The hemlock - white pine - northern hardwoods forest type occupies the northern part of the region. The primary deciduous communities are sugar maple-beech-basswood, sugar maple-beech, and sugar maple-basswood (Braun 1950). American hornbeam occurs as an understory associate in these communities.

LIFE HISTORY

The male and female flowers occur separately, on different trees, and appear in April to early June. The fruits are ribbed nutlets, with bracts borne in catkins; and they ripen in

August to October (*U. S. Forest Service 1948*).

The nut is ovoid, somewhat flattened, ribbed and about 4 mm. long (*Britton 1908*). Numbers of cleaned seed per pound (7 samples) were: low 15,000; average 30,000; high, 45,000. Good seed crops are produced at 3- to 5-year intervals, with light intervening crops. The commercial seed-bearing stage is reached at about 15 years. Production is greatest at 25 to 50 years and probably ceases at about 75 years. Seeds are wind-blown only a short distance, and dispersal is mainly by birds (*U. S. Forest Service 1948*).

American hornbeam may attain a height of 30 to 50 feet and a trunk diameter of 18 inches or more. It has thin, very close and smooth bluish gray bark, often mottled with lighter or darker tints. In the south it is more abundant and attains its largest size. In the northern part of its range it is smaller, with a less symmetrical trunk (*Hough 1907*).

USE BY WILDLIFE

This tree is of secondary importance to wildlife. Ruffed grouse, ring-necked pheasant, and bobwhite quail eat small quantities of the seeds, buds, and catkins. The myrtle warbler eats some seeds; and small amounts of seeds, bark, and wood are eaten by rabbits, beavers, and fox and gray squirrels. White-tailed deer will browse the twigs and foliage (*Martin et al 1951*). American hornbeam has been reported in turkey crops from New York and Pennsylvania (*Korschgen 1967*).

PROPAGATION

Fruits of the American hornbeam should be collected by hand-picking from the tree in late summer or fall before they become dry. Pale greenish-brown color of bracts or involucres and light green-gray color of seeds indicate ripeness (*U. S. Forest Service 1948*).

Seeds collected slightly green may germinate promptly. In one trial, fresh seeds planted on August 19 all germinated the following spring. When gathered, the seeds were immature, just past the "milk stage" (*Titus 1940*).

Fruits that are not to be used for immediate

sowing should be spread out to dry and subsequently placed in a dewinging machine or beaten in bags to separate seed from the involucrum (*U. S. Forest Service 1948*). Also, fruits can be cleaned with a Waring blender in which rubber has been substituted for the steel blades (*Coggleshell 1954*).

The seed can be separated from the chaff by screening and fanning, and stratified in a mixture of sand and peat for overwinter storage. For longer storage it should be sealed in containers soon after collection and stored at 35 to 45°F. (*U. S. Forest Service 1948*).

Seed dormancy may be broken by stratification for 100 to 120 days at 35 to 45°F. in sand or peat, or preferably in a mixture of the two. Sowing may be done in fall or spring. If in fall, seeding should be done in well-prepared beds soon after collection, the seed being covered approximately $\frac{1}{4}$ inch deep with firm soil. Beds should be mulched with burlap, straw, or other material held in place until after the last spring frost. Drills 8 to 12 inches apart are preferred to broadcast sowing. In the spring, stratified seed should be used. Surface soil should be kept moist until after germination, and partial shade is recommended until after seedling establishment (*U. S. Forest Service 1948*).

The optimum natural seedbed for American hornbeam is continuously moist, rich, loamy soil protected from extreme atmospheric changes. Germination occurs from April to June in the spring following seed maturity (*U. S. Forest Service 1948*). Information about seeding in the field is lacking. However, the procedures recommended for nursery use suggest field methods.

MANAGEMENT

Overstory cover is apparently important for the maintenance of American hornbeam. Cutting practices in areas where the trees occur should leave some of the canopy trees for shading purposes.

American hornbeam may be controlled by an application of 2,4,5-T at a concentration of 4 pounds acid equivalent per 100 gallons, diluted in oil. The herbicide may be applied in frills, girdles, or gashes at all seasons of the year (*Rudolf and Watt 1956*).

MISCELLANY

American hornbeam is usually regarded as a weed tree because of its small size and poor form (*Harlow and Harrar 1958*). The tree is of slow growth but very ornamental; its leaves turn orange and scarlet in the autumn. The wood is dense, hard, and very difficult to work

(*Britton 1908*). It is of commercial value for making handles, mallets, and golf-club heads (*U. S. Forest Service 1948*). The nuts are edible by humans, but they are so very small, rarely $\frac{1}{3}$ -inch long, that only in emergency would they be gathered for food (*Fernald and Kinsey 1943*).

HUCKLEBERRIES

BLACK HUCKLEBERRY, *Gaylussacia baccata* (Wang.) K. Koch.
Also called Gueules Noires.

DANGLEBERRY, *Gaylussacia frondosa* (L.) T. & G.
Also called Bluetangle.

BOX HUCKLEBERRY, *Gaylussacia brachycera* (Michx.) Gray.

DWARF HUCKLEBERRY, *Gaylussacia dumosa* (Andr.) T. & G.

By William M. Healy

*Northeastern Forest Experiment
Station
Morgantown, West Virginia*

and

Sadie L. Robinette

*West Virginia University
Morgantown*

RANGE

Black huckleberry is the most important huckleberry growing in the Northeast, and the only one found in all parts of the region. It occurs from Newfoundland to Saskatchewan and south to Georgia, Alabama, Kentucky, and Illinois. Dangleberry grows on Coastal Plain sands from New Hampshire to Florida and occurs inland as far as Ohio, West Virginia, and Tennessee. Where their ranges overlap, dangleberry and black huckleberry usually grow together and respond similarly to forest management.

Two other huckleberries may be encountered. Box huckleberry grows in isolated colonies on dry sites in Maryland, Delaware, West Virginia, Tennessee, and Kentucky. Dwarf huckleberry is restricted to wet, sandy soil and bogs on the Coastal Plain from Newfoundland to Florida (Gleason 1963c).

HABITAT

Black huckleberry is hardy throughout the region, but we found no information about the optimum climatic conditions for the huckleberries.

The habitat of black huckleberry and dangleberry is characterized by soil that is acidic, coarse-textured, and low in nutrients. The sites are usually dry, either because of the coarse soils or because they are in exposed positions (Reiners 1965). Acid soil seems to be essential; huckleberries planted in neutral or basic soil fail to grow (Wherry 1957). Black huckleberry grows best in soil with a pH of 4.0 to 5.0, while 4.5 to 6.0 is optimum for dangleberry (Spurway 1941).

Black huckleberry, lowbush blueberry (*Vaccinium angustifolium* Ait.) and early sweet blueberry (*V. vacillans* Torr.) often form a dominant shrub community on Coastal Plain

sands in New Jersey, New York, and New England (Reiners 1965); on sandstone ridges in Connecticut, New York, Pennsylvania, and western Maryland (Nichols 1914); and on sandy and peaty soils of the Lake States (Hosley 1938) and other similar habitats in the Northeast (Reiners 1965). This huckleberry-blueberry community occurs both in openings and beneath forest stands. It often starts as a pioneer or early successional stage and then persists as the forest develops on dry sites. The timber stands that overtop huckleberries characteristically have thin, open canopies (Reiners 1965).

It is not known if huckleberries are restricted to dry sites because of moisture relations, or because trees on dry sites produce canopies that considerable light penetrates (Reiners 1965). Oak-hickory, chestnut-oak, oak-pine and pine-scrub oak are the common forest types that have a huckleberry-blueberry shrub layer; and the dominant trees are pignut and shagbark hickories, white, scarlet, chestnut, and black oaks, and pitch and shortleaf pines (Brayton and Woodwell 1966, Nichols 1914, Reiners 1965, Stephenson 1965). Next to the blueberries, bear oak is probably the most common shrub associate of huckleberry. In openings, huckleberry grows with sweetfern, chokecherry, smooth sumac and shining sumac; and in oak-hickory stands, flowering dogwood, eastern hop hornbeam, tea-berry, mountain-laurel, and rhododendron are frequent associates. Dangleberry is a common associate but rarely a dominant shrub in the huckleberry-blueberry community on Coastal Plain sands.

Huckleberry-blueberry stands often develop after burning. Both shrubs sprout readily in response to fire, and thrive if burning is neither frequent nor severe (Brayton and Woodwell 1966). Controlled burning in the New Jersey Pine Barrens at 3-year intervals reduced shrub cover by one-half, but the relative importance of early sweet blueberry increased while black huckleberry and dangleberry decreased (Buell and Cantlon 1953). In general, burning more than once every 5 years favors early sweet blueberry over black huckleberry and dangleberry (Brayton and Woodwell 1966). Protection from fire for a

decade resulted in a decrease in density of the shrub layer in some oak-pine communities in the New Jersey Pine Barrens. Like most shrubs, black huckleberry decreased in density, but it increased in relative importance over early sweet blueberry. Dangleberry decreased significantly (Stephenson 1965).

LIFE HISTORY

Specific life-history information was found only for black huckleberry. Leaf bud-break and flowering both begin about the first week of May, slightly later than the blueberries. The flowers last through June, and the berries mature by the end of July. The berry is black and contains 10 seeds, each about 1/16 inch long. Huckleberries remain on the plants from July to September, but ruffed grouse stomach records commonly show seeds through November (Hosley 1938). The many birds and mammals that eat huckleberries probably are responsible for the dissemination of seeds, but the effect of passage through their digestive tracts is not known (Reiners 1965).

Insects pollinate the flowers. Despite large fruit crops, seedlings are rare. New colonies are established from seed, but reproduction and spread of existing colonies is almost entirely through growth of the root system. Slender branched roots grow in all directions from the main roots. These occasionally produce aerial shoots, and injuries to the root system or destruction of above-ground stems will stimulate sprouting from the roots (Reiners 1965).

In the Pine Barrens of Long Island, New York, 1-year-old black huckleberry stems were unbranched and up to 7.8 inches tall. As they grew older, the stems produced many side branches. The result was a dense, twiggy canopy 12 to 39 inches tall, depending on site conditions. Ring counts revealed an average stem age of 5.7 years and a maximum age of 15 years (Reiners 1965). Fruit production begins when stems are 3 years old (Spinner and Ostrom 1945).

Black huckleberry is intermediate in tolerance to shading (Davidson 1966, Hosley 1938). Partial cuttings of the overstory usually favor huckleberry, but competition from other shrubs may be as important as

overhead shade. In one experiment in the Pine Barrens of New Jersey, black huckleberry decreased while blueberry and other shrubs increased after removal of overstory oaks (*Buell and Cantlon 1953*).

In unburned stands, black huckleberry usually overtops lowbush blueberry, but it generally does not completely overtop early sweet blueberry (*Reiners 1965*).

USE BY WILDLIFE

The huckleberries are important for cover, for fruit, and for browse production. Together with the blueberries and bear oak, black huckleberry provides low cover for song birds and small mammals over extensive areas of dry open woodland in the Northeast. Its food value is largely restricted to the fruits, but it provides some browse. The fruits ripen in summer along with the blueberries, and in general, wildlife and humans prefer the less seedy blueberries to the huckleberries.

Black huckleberry and dangleberry fruits are eaten by sharp-tailed grouse, greater prairie chicken, bobwhite quail, wild turkey, mourning dove (*Van Dersal 1938*), and at least 7 song birds, including the catbird and scarlet tanager (*Martin et al 1951*). The Ruffed grouse eats the fruit in summer and buds in winter, but black huckleberry is a food of secondary importance (*Brown 1946, Edminster 1947, Hosley 1938*). White-tailed deer and cottontail rabbits browse huckleberry stems lightly in most of the Northeast (*Martin et al 1951, Trippensee 1938, Van Dersal 1938*), but occasionally cottontails severely damage black huckleberry stems during winter (*Sweetman 1949*). The black bear, gray fox, and fox squirrel also eat huckleberry and dangleberry fruits (*Hosley 1938, Martin et al 1951*).

PROPAGATION

Nursery manuals usually treat huckleberries as a genus and state that they are propagated in the same way as blueberries (*Bailey 1950:317, Laurie and Chadwick 1931, Sheat 1953*). The usual methods of propagation are: (1) from seed sown under glass in winter or spring, (2) from hardwood and softwood cuttings, (3) by division in fall and spring, and

(4) by layering in spring and summer. The vegetative methods are the same for all species.

Specific information about propagation from seed was found only for black huckleberry. Seeds can be obtained by harvesting ripe fruit with a blueberry rake and extracting the seed by macerating the berries in water and floating off the pulp. Sound seed will settle to the bottom. Yields were approximately 3 pounds of cleaned seed per 100 pounds of fruit, and the number of cleaned seed per pound ranged from 281,700 to 412,000 (*Swingle 1939, U. S. Forest Service 1948*). Seed has been air-dried and stored in sealed bottles at 41°F for 2 years without loss in viability (*U. S. Forest Service 1948*).

Cleaned seed should be sown in an acidic mixture of sand and peat. In one study, good germination was obtained with seed that had been stratified for 30 days at temperatures alternating diurnally from 68 to 86°F and then held at 50°F. Germination began between 8 and 27 days and was complete by the 47th day after the start of the 50°F stratification (*U. S. Forest Service 1948*).

Although we found a statement that all huckleberries can be propagated from seed sown under glass in winter or spring (*Van Dersal 1938:135*), we also found an indication that box huckleberry clones may be self-sterile (*Coville 1919, Wherry 1934*). About 90 percent of the seeds from one isolated box huckleberry clone were empty shells. Only 3 seeds germinated from 1,600 sown in November on a suitable soil of peat and sand. July plantings also gave poor results, and the author believed that individual plants were sterile to their own pollen (*Coville 1919*). Because box huckleberry usually occurs as a clone, it is a good idea to test seed sources for germination before attempting nursery production.

MANAGEMENT

Black huckleberry will often be managed as part of a huckleberry-blueberry shrub community. Light burning in the spring at 2- or 3-year intervals will favor blueberries, while burning at intervals of 5 years or longer will favor huckleberry. Complete removal of the overstory will increase the relative importance

of blueberries, but partial cuttings usually favor huckleberry (*Buell and Cantlon 1953, Stephenson 1965*).

Huckleberry clones can be rejuvenated by removal of competing vegetation, light burning, or shallow cultivation and cutting back the tops of the plants. Stands can be enlarged by removing encroaching vegetation and then lightly cultivating or layering the plants at the edge of the stand.

Black huckleberry is useful for erosion con-

trol because it grows on sterile acid soils, which often present planting problems (*McAtee 1936*). Its attractive foliage, flowers, fruit, and low growth form make it suitable for ornamental plantings. Box huckleberry has also been recommended as an ornamental ground cover. It has attractive evergreen foliage, usually grows only 6 to 12 inches tall, and thrives in the shade (*Curtis and Wyman 1933*).

MAPLES

MOUNTAIN MAPLE, *Acer spicatum* Lam. Also called Low Maple, Moose Maple, and Water Maple.

By Paul E. Hosier

Department of Botany, Duke University
Durham, North Carolina

RANGE

Mountain maple is found in all the northeastern states and provinces. It occurs from Newfoundland to Saskatchewan, south to Connecticut, Ohio, Michigan, and northern Iowa, and in the mountains to western North Carolina and eastern Tennessee (Gleason 1963b).

HABITAT

Mountain maple thrives in a humid climate that has adequate precipitation in all seasons. The snow-cover period ranges from about 30 days in the southern part of the range to more than 120 days in the extreme northern part. The growing season lasts from less than 120 days to more than 170 days (Van Dersal 1938). The average January temperatures range from 0 to 40°F., and the average July temperatures range from 60 to 75°F. within the range of the species. Extreme temperatures in its range are -50 and 105°F. The precipitation average varies from about 25 to 30 inches (U. S. Department of Agriculture 1941).

Mountain maple has medium moisture and nutrient requirements and low heat and light requirements (Bakuzis and Hansen 1959, Krefting et al 1966). In the north, it prefers

rich soils on moist rocky slopes and flats and along streams (Vincent 1965) but grows well in drier or well-drained acid soils (Van Dersal 1938). In the Appalachians it is widely distributed and locally common at 2,500 to 4,200 feet in elevation (Van Dersal 1938).

Mountain maple is a prominent understory tree of the maple-beech-basswood forest, the birch-hemlock-spruce forest, and the northern conifer types (Shelford 1963). It is a member of the mixed mesophytic type at higher elevations of the Appalachians and the red oak-birch and red oak-basswood forest of the mountains of Pennsylvania. It is also found in the beech-maple forest of the Great Lakes area and the hemlock-white pine-northern hardwoods forest (Braun 1950).

LIFE HISTORY

Mountain maple flowers from May till June (U. S. Forest Service 1948). After the leaves are fully grown, the flowers are produced in a narrow, erect, long-stalked, terminal cluster. The male flowers are borne near the tip of the cluster, the female flowers near the base. The fruit is a double samara about $\frac{1}{2}$ -inch long (Palmer 1949). The seeds ripen between mid-September and mid-October.

No data were found about the quantity of

seed produced per tree. Wind is the primary factor in spreading the seeds. Stems of seedling origin are rare, suggesting that seedling mortality is high under natural conditions (*Krefting et al 1966*).

Mountain maple attains a maximum height of 30 feet in the Appalachian Mountains, but tends to be smaller, about 20 feet, in the north. The tree has a short bole, which may become 6 to 8 inches in diameter in the south but seldom exceeds 3 to 4 inches in the north. It commonly forms clumps, each member having several upright branches, which produce many branchlets and form a bushy head (*Harrar and Harrar 1946*). Reproduction is most commonly by sprouting from the stem, including stems growing laterally underground, or from layering of branches in contact with the ground. Seedling reproduction is usually scarce and root suckers may be rare (*Post 1965, Post 1969, Vincent 1965*). The stems produce buds that tend to remain dormant until they are disturbed by cutting or browsing (*Krefting et al 1966*).

In Ontario and New Brunswick, senile mountain maples (40 to 50 years old) produced more new vegetative growth than younger plants. This suggested that a factor inhibiting growth is present in living stems but disappears as they approach death (*Vincent 1965*).

Height growth averaged about 1 foot per year, and the most rapid growth was from 5 to 10 years. Shoots from the lower portion of parent stems grew faster than other types of shoots. Stand densities were as high as 40 square feet of basal area per acre. Heights of the tallest stems did not seem to be related to age or origin (*Vincent 1965*).

Mountain maple can grow in either sunlight or shade, but grows best if neither is extreme. It is able to tolerate strong sunlight better than striped maple (*Palmer 1949*) and is about equal to balsam fir and red spruce in light requirements (*Post 1969*). Successionally, it usually comes in after openings in the overstory of the forest are produced. In virgin forest tracts, it has been known, along with striped maple, to form a distinct understory in the forest (*Braun 1950*). When released, by logging or other means, mountain maple may

dominate the site within 5 to 10 years and may suppress competing species, particularly spruce and balsam fir, for at least 35 years (*Vincent 1965*).

USE BY WILDLIFE

Deer and moose browse the bark and twigs of mountain maple, and beavers utilize the bark, particularly where aspen is lacking. Cottontail rabbits also browse on the plant (*Van Dersal 1938*). The buds are eaten by ruffed grouse (*Peattie 1950*).

PROPAGATION

The ripe seed of mountain maple may be collected from standing trees or gleaned from trees felled in logging operations (*U. S. Forest Service 1948*). The seeds, as well as seedlings, may be available commercially (*Mattoon 1958*). I found no information about the minimum seed-bearing age for mountain maple. Commercial seed was 93 percent pure and had a soundness average of 73 percent (range 57 to 84). The number of cleaned seeds per pound varied from 15,300 to 27,800, with an average of 22,000 (*U. S. Forest Service 1948*).

In nursery practice, seeds can be sown in either fall or spring. For sowing shortly after seed collection, the seeds should be pretreated by soaking in water, changed daily, for a week (*Heit 1968*). For spring sowing, the seeds should be scarified and stratified over winter. Since the samara husk and the seed coat act to delay germination, the husk should be removed and the seed coat should be scratched. Seeds should then be stratified in sand at 41°F. for 90 to 120 days. Data on germination are meager, but suggest that nearly all germination occurs within a month and that germinative capacity may be as low as 0 to 34 percent (*U. S. Forest Service 1948*).

Seeds that have been air-dried can be stored at low temperatures (41°F.) in sealed containers, but they do not store as well as seed of most other maples. Mountain maple seed lots stored for 2 years lost three-quarters of their original germinative capacity (*U. S. Forest Service 1948*). Some seed lots stored fresh (immediately after collection) germinated 1

year later in sealed containers in a 35°F. cold-room (*MacArthur and Fraser 1963*).

The seed should be sown about $\frac{1}{4}$ to 1 inch deep in mulch beds and sown either in drills or by broadcasting. For best growth the seedbeds should be shaded. One-year-old seedlings are usually large enough for outplanting (*U. S. Forest Service 1948*).

For propagating mountain maple vegetatively, layering may be practical, but use of cuttings apparently is not. Root and shoot cuttings tested in New Brunswick yielded less than 1 percent success. Fresh root and stem cuttings were planted weekly in an outdoor nursery during April-November. Recent-growth stem cuttings were dipped in a commercial hormone preparation and planted in vermiculite. Also, roots were severed from the stem and left in place. None of these treatments was effective (*Post 1969*).

Layering is common in the wild, and layering methods seem promising for artificial propagation. For example, a mountain maple that had been tipped by a bulldozer so that its crown was pressed tightly on the ground produced nearly 50 vigorous shoots, some of which grew 13 inches during the first year (*Post 1969*). I found no reference to intentional propagation by layering.

MANAGEMENT

Mountain maple is one of the most nutritious and palatable browse plants for deer. It withstands repeated and heavy browsing and actually produces the most browse when about 80 percent of the annual twig growth is re-

moved each year. If not heavily browsed, it often grows out of the reach of deer within 3 years (*Aldous 1952, Krefting et al 1966*).

In Minnesota, Krefting compared several top-killing treatments for stimulating regrowth. Cutting the stems with an ax near ground level during the dormant season was most effective. The second best treatment was breast-height spraying of the bark, until runoff, with 2,4-D (at least 12 pounds of acid per 100 gallons of No. 1 diesel oil). Spring treatment, at early bud-burst time, yielded more regrowth than fall spraying. Deer readily browsed the regrowth. Costs of cutting and spraying were about equal, but cutting produced more regrowth and had the added advantage of making much of the cut browse immediately available to deer (*Krefting et al 1966*).

Bulldozing can be used to either stimulate new growth in an aging stand or for eradication. If eradication is desired, the plants should be uprooted or the stems should be severed, or both (*Post 1969*). This treatment was considered less expensive than herbicides applied to the soil. If stimulation of new growth is desired, the plants should be tipped and the crowns mashed down, but complete uprooting and severing of main stems should be avoided.

Burning can be used to suppress mountain maple. After logging, slash should be piled on the maple thickets and burned. Where the thickets are scattered or are on rocky slopes, this treatment may be cheaper than bulldozing (*Post 1965*).

STRIPED MAPLE

STRIPED MAPLE, *Acer pensylvanicum* L. Also called Goosefoot Maple, Maleberry, Moosewood, Northern Maple, Striped Dogwood, and Whistlewood.

By Paul E. Hosier

Department of Botany, Duke University
Durham, North Carolina

RANGE

This species is found throughout most of the Northeast, from Nova Scotia and the Gaspé Peninsula to Ontario and central Michigan, from New England south to Ohio and Pennsylvania and in the mountains to northern Georgia (Little 1953).

HABITAT

Striped maple grows in regions that are relatively humid and provide frequent precipitation during all seasons. The frost-free period ranges from less than 100 days in the northern part of the range to nearly 200 days at the southern limit. The number of days of snow cover ranges from 120 to 60 days, north to south (Van Dersal 1938).

This species prefers acid soils (Wherry 1957); however no information was found to establish its pH tolerance range or the optimum pH. It prefers sandy loam soils that are moist but well drained (Van Dersal 1938). The tree grows well on rocky and exposed mountain slopes and on rock slides that are more or less soil-covered (Braun 1950). In the southern Appalachians, striped maple prospers up to 4,500 feet in altitude on south-facing slopes and is common from 2,500 to 4,200 feet

in the mountains of West Virginia (Shelford 1963).

Striped maple is considered an understory tree because it rarely attains the height of a canopy tree. In virgin forest tracts, striped and mountain maple may form a distinct low layer of vegetation (Braun 1950). Striped maple is associated with these forest types: maple-beech-basswood, birch-hemlock-spruce, mixed mesophytic, oak-chestnut, and hemlock-white pine-northern hardwoods (Shelford 1963).

LIFE HISTORY

Individual striped maples usually bear two kinds of flowers: some bi-sexual and others male only. The bright yellow flowers are borne singly on a drooping terminal cluster. Each cluster is usually either wholly male or bi-sexual. Flowers bloom from May to mid-June (Palmer 1949). The seeds ripen between September and mid-October and are disseminated in October and November (U. S. Forest Service 1948). The agent of natural dissemination is wind.

Mature trees may attain a height of 30 to 40 feet and a diameter of 8 to 10 inches (Harrar and Harrar 1946). Striped maple does not grow best in strong sunlight. It prefers the

shade of other trees, but will show a rapid increase in height if it has been densely shaded and then released by overstory thinning. However, if the sunlight is too strong, striped maple may be replaced by mountain maple where the latter species is established.

USE BY WILDLIFE

In winter, the twigs are consumed by white-tailed deer, ruffed grouse, and moose; and porcupines eat the bark. In summer, the leaves are eaten by moose and deer. Squirrels, chipmunks, and ruffed grouse eat the seeds (*Martin et al 1951; Bump et al 1947*). When aspen is lacking, beavers forage upon striped maple. Cottontail rabbits also eat striped maple (*Van Dersal 1938*). Several species of birds use the seed stalks and the leaves for nesting material (*Martin et al 1951*).

PROPAGATION

The seed or seedling stock of this species is not usually available from commercial growers. Seed may be collected from standing trees or taken from the branches soon after the trees are felled. Studies have established the soundness of commercial seed at 79 to 95 per-

cent. The number of cleaned seeds per pound varies from 9,700 to 15,600, with an average yield of 11,500 seeds per pound. Seeds can be stored moist in sealed containers at 41°F. for at least 18 months (*U. S. Forest Service 1948*).

In the nursery, the seeds are usually sown in the fall in mulchbeds to effect stratification. Most germination takes place early in the spring; however, some germination may be delayed because of dormant embryos. Growth of the seedlings is enhanced by shading the mulched beds.

The seeds can be stratified artificially by placing them in moist sand at 41°F. for 90 to 120 days. The stratified seed is then sown in the spring, $\frac{1}{4}$ inch to 1 inch deep. Within a few weeks, the seeds germinate. Germination experiments show 40 to 80 percent germination. The seedlings are relatively free of insect or fungus diseases (*U. S. Forest Service 1948*).

I found no literature about field propagation of striped maple.

MANAGEMENT

I found no literature specifically about management of striped maple.

MOUNTAIN-ASHES

AMERICAN MOUNTAIN-ASH, *Sorbus americana* Marsh. (*Pyrus a.* (Marsh.) D.C.) Also called American Mountainash, American Rowan Tree, American Service Tree, Dogberry, Indian Mozemize, Life-of-Man, Masse-Misse, Missy-Massy, Missey-Moosey, Mountain Ash, Mountain Sumach, Quick Beam, Round Tree, Roundwood, Service Tree, Small Fruited Mountain Ash, Wild Ashe, Wine Tree, and Witchwood.

SHOWY MOUNTAIN-ASH, *Sorbus decora* (Sarg.) Schneid. (*Pyrus d.* (Sarg.) Hyland) Also called Large Fruited Mountain-Ash and Roundwood.

EUROPEAN MOUNTAIN-ASH, *Sorbus aucuparia* L. (*Pyrus a.* (L.) Gaertn.) Also called Rowan-Tree.

By Steve Eabry

New York Department of Environmental Conservation
Delmar

RANGE

These are all northern forms; their occurrence in the southern parts of their ranges is spotty—mostly at cold, wet, rocky sites. American mountain-ash occurs in all states and provinces of the Northeast. Showy mountain-ash occurs in all the provinces, Newfoundland to Ontario, and south into the northern states, Maine to Northern Indiana. The naturalized range of European mountain-ash is similar to that of showy mountain-ash but extends a little farther south (*Gleason 1963b*).

HABITAT

These mountain-ashes occur naturally in a north temperate climate. Warm temperatures probably limit all three species. They prefer

moist situations, although they are also found on elevated slopes. American mountain-ash is found near sea level in southern Greenland (*Shelford 1963*) and at elevations of 6,000 feet in North Carolina (*Sargent 1922*).

The mountain-ashes grow best on rich, moist soil; but they also prosper at higher elevations on relatively poor sites with thin soil and on rocky areas (*Braun 1950*). The optimum pH range for American mountain-ash has been reported as 4.5 to 6.5 (*Spector 1956*) and 4.5 to 5.5 (*Spurway 1941*). Soil samples collected throughout Wisconsin from areas supporting vigorous fruit-bearing American mountain-ash had an average pH of 4.9 ± 0.09 , but soils in the 4.7 to 6.0 pH range were recommended for planting (*Wilde 1946*). European mountain-ash prefers a pH between 5.5

and 7.5 (*Spector 1956*). Soils saturated for more than a day or two seem to be harmful to seedlings (*Lawyer 1968*).

All three mountain-ashes are shrubs of climax and subclimax northern coniferous forest communities, along with speckled alder, Labrador tea, mountain and red maples, yellow birch, and bunchberry. American mountain-ash is also found in shrub types of the Appalachian mountains with mountain laurel, rhododendrons, blueberries, greenbriers, balsam fir, and yellow birch (*Shelford 1963*).

LIFE HISTORY

All species have flattened clusters of white flowers. Flowering occurs from May to July, after the plant is fully leaved. The fruits of the European and showy mountain-ashes ripen in August or September; those of the American mountain-ash ripen a little later, some into October (*U. S. Forest Service 1948*). The bright red, berrylike fruits of showy mountain-ash are 7 to 10 mm across, European 8 mm, and American 4 to 6 mm (*Rehder 1940*). Fruits are usually two- to five-celled with one or two seeds in each cell (*U. S. Forest Service 1948*).

Information about seed production by American and showy mountain-ashes is lacking. European mountain-ash seed crops are variable; in yearly measurements of five plants at the Kellogg Forest in Michigan, yields ranged from 0 to 0.36 pounds of fruit per square foot of crown, with a mean for 8 years of 0.14 pounds (*Gysel and Lemmien 1964*).

There have been no studies to determine if there are climatic races in American or showy mountain-ash, but races probably have developed in the native trees of Europe (*U. S. Forest Service 1948*).

Natural seed dispersal is chiefly by birds, with a little help from small mammals. The mountain-ashes reproduce mainly from seed. They usually will not grow from cuttings. Layering is difficult and often yields poor results. However, they graft easily (*Lawyer 1968*).

American mountain-ash has a relatively rapid growth rate, reaching an average height of 25 to 30 feet (*Spector 1956*). It starts growing early (mid-April in Massachusetts) and continues to early August, with 90 per-

cent of the growth occurring during 39 days from 1 May to 9 June (*Kozlowski and Ward 1957*). European mountain-ash has a moderate growth rate and reaches 20 to 40 feet (*Spector 1956*). It starts bearing fruit at about 15 years (*U. S. Forest Service 1948*), and may live about 80 years (*Spector 1956*).

The mountain-ashes are intermediate in shade tolerance (*Spector 1956*), sometimes growing under a fairly dense forest canopy, but more often in openings. Except on an ideal site, seedlings probably cannot compete with a dense herbaceous growth. Even 8-inch nursery stock all but failed when planted in sod on poor soil (*Cook and Edminster 1944*).

USE BY WILDLIFE

In Wisconsin, deer ate the leaves and tips from American mountain-ash in spring and summer, and browsed it in the fall. It was classed along with 7 other species as first choice in a palatability rating of 32 winter deer browse species (*Dahlberg and Gruetinger 1956*). Mountain-ash is rated as a deer food "... species in short supply but generally accepted as preferred ..." in New Hampshire (*Laramie 1968*) and also in Wisconsin (*Beals et al 1960*). In Newfoundland, American mountain-ash was browsed by both moose and snowshoe hare, and was a favored food of both (*Dodds 1960*). It was sufficiently attractive to cottontails in Massachusetts to suffer considerable injury during the winter months (*Sweetman 1944*). American mountain-ash berries were the sixth most common food of spruce grouse in Ontario before the first snow. However, the berries did not occur in any of the 37 crops collected after the first snow (*Crichton 1963*). Ruffed grouse and songbirds, especially evening and pine grosbeaks, and cedar waxwings, are regular feeders on mountain-ash berries (*Martin et al 1951*). Showy mountain-ash fruits in the Albany, N. Y., area are eaten by starlings and robins as soon as the fruits start to color and soften. There are usually no fruits remaining by 1 September (*Ralph Smith, personal communication*). These birds usually consume all the mountain-ash fruits by early fall at the Arnold Arboretum (*Fordham 1967*).

Mountain-ashes are not particularly valua-

ble as wildlife cover except where they and associated species form thickets.

PROPAGATION

Seeds of these three mountain-ashes are normally available from at least three commercial sources (in Massachusetts, New York, and Pennsylvania), and plants are available from many nurseries. Addresses can be obtained from the Soil Conservation Service (1971).

Fruits may be picked in the field as soon as ripe and run either through a macerator to remove the pulp or through a fruit press. In the latter process, the fruit should be dried and the seed can be broken out by hand as it is sown. Fruits may also simply be spread out to dry and used in that form (U. S. Forest Service 1948).

The yield of seed per bushel of fruits was: American 1 to 2 pounds, European 3 to 7 pounds, and showy mountain-ash unknown. The number of cleaned seeds per pound is also variable. The following figures have been reported for American mountain-ash: an average of 160,000 (U. S. Forest Service 1948), 83,000 to 100,000 (Van Dersal 1938) and 83,500, 160,640, and 236,300 from three sources (Swingle 1939). The number of clean European mountain-ash seeds per pound has been given as about 104,000 (Swingle 1939, Van Dersal 1938) and as an average of 130,000 (U. S. Forest Service 1948). Showy mountain-ash averages 127,000 clean seeds per pound (U. S. Forest Service 1948).

Storage of European and American mountain-ash seeds at ordinary room conditions is usually satisfactory in either sealed or open containers, but temperatures below 70°F and about 25 percent relative humidity are recommended. Storage information for showy mountain-ash is lacking.

Mountain-ash seeds exhibit embryo and seed-coat dormancy. Untreated fruit or seeds sown in late fall or winter usually do not germinate until the second or third spring (U. S. Forest Service 1948). Germination can be hastened by cleaning the seed and sowing in late September (or by October 15 at the latest), or by spring sowing after stratifying the seed in

moist sand for 90 days at 68 to 86°F, then for 90 days at 41°F (Heit 1967c, Heit 1968, U. S. Forest Service 1948). Seed may be sown broadcast or in drills and should be lightly covered with about 1/16 inch of soil.

The yield of usable plants per pound of seed in one study was 225 for American mountain-ash and 2,090 for European mountain-ash (Bennett 1939). In another study, about 5,000 usable plants (species not reported) were obtained per pound of clean seed when seed was sown at the rate of 6 to 8 ounces per 100 square foot of seedbed. The best growing density was 20 plants per square foot (Bump et al 1947).

In nurseries, the mountain-ashes "like lime" and seem to deplete the seedbeds by taking unknown growth factors from the soil (Lawyer 1968). The seedlings are quite hardy and resistant to insects or diseases. However, they are attractive foods of deer and snowshoe hare, and may have to be protected where the chance of browsing is high. For field planting, 1-1 stock is best, but 2-0 is often suitable. Best results are obtained by planting on cool, moist sites. Natural seedlings are most common near the parent tree, on exposed mineral soil, and where some protective shade is available (U. S. Forest Service 1948).

Seedlings grown in the shade or crowded in the seedbed often develop thin bark. When planted they should be shaded to prevent damage from sunburn (Lawyer 1968).

MANAGEMENT

Need for care in selecting planting sites and protecting the seedlings from browsing was shown in a New York study (Cook and Edminster 1944). European and American mountain-ash seedlings about 8 inches tall were planted in poorly drained, sterile, generally acid soils on abandoned farmland. After 3 years, the highest survival (50 to 75 percent) was on land plowed before planting. Survival on scalped land was 30 to 70 percent, and for those planted in slits in the sod, survival was less than 10 percent. Both species grew feebly, scarcely maintaining their initial height. Twenty years after planting, the mountain-ashes had become smaller because of deer

browsing, and Smith (1964) concluded that the ". . . susceptibility of both to stem borers makes them poor materials for wildlife plantings." Although stem-borers may kill the shoots of mountain-ashes that are growing slowly, the plants often recover by sprouting (*Ralph Smith, personal communication*).

Several state agencies are working with species and varieties of mountain-ash from Europe and Asia. The aim is to find good fruit-producing forms suited to particular areas. Few conclusions have been reached, and seed or plant sources are limited; but stock better

suited to local conditions may be found and made available in the future.

Established plants should be stimulated to develop large crowns by killing or cutting back competition. It is not necessary or desirable to entirely open up the area around and over the plants. Natural seeding might be encouraged by exposing mineral soil near seed sources during good seed years. Protection of seedlings and saplings from browsing might also be practical for several years.

If control were ever necessary, girdling or application of an herbicide would be sufficient.

MOUNTAIN-LAUREL

Kalmia latifolia L.

Also called Calico-Bush, Ivy, Ivy Bush, Laurel, and Spoonwood.

By Sadie L. Robinette

West Virginia University
Morgantown

RANGE

Mountain-laurel is native to the Atlantic Coastal Plain and Appalachian Mountains from Maine to Florida and west to Indiana and Mississippi (*Kurmes 1961, U. S. Forest Service 1948*).

HABITAT

Optimum climatic conditions for the growth of mountain-laurel have not been determined, but thickets reach their largest size in the southern Appalachians of West Virginia, Virginia, and Kentucky. Mountain-laurel occurs naturally on acid soils, usually within the pH range of 4.0 to 6.5 (*Kurmes 1961, Spurway 1941*). Where acid conditions exist, it will grow on rocky, gravelly, sandy, or peaty soils in a variety of sites. Soil moisture is an important factor in distribution. Survival in the first year after germination depends on a good moisture supply to the small, shallow root system. Mountain-laurel reaches its greatest size on moist sites, and rarely occurs on boggy saturated soils (*Kurmes 1961*).

From the Catskill region south through the Appalachians, mountain-laurel is a common

understory plant of oak and mixed hardwood forests on acid sites. It is usually associated with other heath shrubs. In the Catskills, mountain-laurel, blueberries, azaleas, and tea-berry are abundant on lower slopes beneath mixed hardwoods. Heath communities occur on all the ridges of the ridge and valley area of Pennsylvania, West Virginia, Virginia, and Maryland. In this region, mountain-laurel, blueberries, and huckleberries appear to have invaded the openings left by dying American chestnut trees (*Braun 1950*).

Approximately 3 million acres of southern Appalachian mountain lands are occupied by stands of mountain-laurel and rhododendrons (*Wahlenberg and Doolittle 1950*). Laurel, rhododendron, and several species of azalea and blueberry are the dominant shrubs of the heath barrens which occur in the mountains of West Virginia (*Core 1966:55*). Scrub oaks, laurel, and other heaths are also some of the most abundant shrubs of the New Jersey Pine Barrens (*Braun 1950:270*).

LIFE HISTORY

Flowering occurs from early May in the southern Appalachians to late June in New

England. Insects pollinate the showy pink to white blooms, which remain for 2 to 3 weeks. Seeds mature in small five-part capsules, which may contain more than 700 seeds, but average 500 to 600. The dustlike seeds are less than 0.04 inch long and 0.02 inch in diameter. Despite their small size, wind scatters them relatively short distances, and seedlings are rarely found more than 50 feet from mature plants. Seedfall begins in November and continues until spring. Seeds remain alive through the winter in the capsules and on the forest floor (Kurmes 1961).

Mountain-laurel regenerates by seeds, layers, sprouts, and suckers. Flowering is much more profuse in open sunlight than in partial shade and rarely occurs in deep shade (Kurmes 1961). Production of new stands by seeding usually occurs after logging, fire, or other disturbance (Chapman 1950). In Connecticut, most natural seedlings were found on beds of dense, low moss. Several species of low moss commonly occurred where the forest floor had been disturbed, and they provided a stable, moist bed for laurel seeds. Germination also occurred on bare mineral soil; survival was rare where thick litter, deep moss, or other plants covered the soil (Kurmes 1961). Increase in stand density and lateral spread appear to be caused by a combination of seeding and natural layering (Kurmes 1961, Little 1944). Laurel sprouts vigorously from dormant buds along the stem or the root burl after injury by fire or cutting (Kurmes 1961).

Growth rate of laurel depends on site conditions. Generally, sprouts grow faster than seedlings, and growth rate declines with age. In the southern Appalachians, stands averaging 8 feet tall were about 20 years old, with a mean annual height growth of 0.4 foot (Wahnenberg and Doolittle 1950). In Connecticut, laurel stands were about 6 feet tall when 30 to 45 years old, but when these stems were cut to the ground the sprouts grew 17 inches tall in 4 years (Chapman 1950). One-year-old seedlings growing beneath a hardwood overstory averaged less than 1 inch tall (Kurmes 1961: 23).

The life span of mountain-laurel thickets and stems is probably as variable as the growth rate. In Connecticut, 35- to 45-year-

old thickets were still growing taller; and in the southern Appalachians 60-year-old stands are common (Chapman 1950). One 110-year-old laurel stem has been reported (Kurmes 1961).

Mountain-laurel is moderately shade-tolerant, but growth is more vigorous in the open. Seed germination apparently is best in partial shade, but under heavy shade laurel plants produce few flowers and eventually die (Eiser 1961).

USE BY WILDLIFE

Mountain-laurel provides valuable winter cover for white-tailed deer, eastern cottontails, snowshoe hares, and ruffed grouse, especially where it is the major evergreen ground cover. Acetyl andromedol, a resinous substance in the leaves, twigs, and nectar of mountain-laurel, is poisonous to livestock (Hardin 1966). Sheep, goats, cattle, and possibly horses have died from eating laurel, but wild animals are not poisoned (Hardin 1966, Marsh 1930:19). Sixteen white-tailed deer fed nothing but mountain-laurel and rhododendrons for 45 days became thin and weak, but showed no sign of poisoning (Forbes and Bechdel 1931). One deer died after being force-fed laurel leaves equivalent to 1.75 percent of its live weight; a second deer recovered from a dose equivalent to 1.29 percent of its body weight (Forbes and Bechdel 1931).

White-tailed deer eat small amounts of laurel foliage wherever it is found; but in West Virginia, laurel and rhododendron appear to be preferred foods (Core 1966:22). Mountain-laurel is one of the 25 most important grouse foods in the Northeast. Leaves are eaten during fall, winter, and early spring when green leaves of most other plants are lacking (Edminster 1947:121). Black bears eat small amounts of leaves, buds, and capsules (Martin et al 1951:352-3).

PROPAGATION

Seeding, layering, and cuttings are the major means of propagating mountain-laurel. The vegetative methods are used for preserving genetic traits; seeding is best for quantity production. Mountain-laurel seeds (and

plants) are available from commercial nurseries, or ripe brown capsules may be collected from local plants from September through January. Capsules should be airdried, crushed, and shaken through a 0.0197-inch (0.5-mm) mesh screen to separate the seeds from the chaff (*Kurmes 1961*).

Seed storage conditions do not appear to be critical. One study found no difference in germination between seeds stored for 10 weeks at sub-freezing temperatures and those kept under warm dry conditions (*Kurmes 1961*). Others recommend exposing laurel seeds to outdoor winter temperatures for 2 or 3 months before sowing (*Wells 1955, U. S. Forest Service 1948*).

Seeds are normally sown in the greenhouse in late March or early April. An equal mixture of sand and peat, sifted sphagnum or peat, and living low mosses, all make good seedbeds (*Kurmes 1961*). Sandy soil can also be used, but hardwood leaf litter is not suitable (*U. S. Forest Service 1948, Kurmes 1961*). Germination occurs in 2 to 2½ weeks and may be as high as 90 percent (*Kurmes 1961*). Seedlings should be removed from the seedbed when 3 months old, or after the first true leaves appear. It is best to move plants directly outside to a shade-house or frame, but they can be kept in the greenhouse until the following year.

Seedlings kept in the greenhouse should be planted at least 1½ inches apart in flats containing an equal mixture of sand and peat moss. They should be shaded during the summer, and the temperature should be kept near 60°F. Keeping plants in the greenhouse until they are a year old often requires additional transplantings (*Laurie and Chadwick 1931: 142*). Direct transplanting from seedbed to shade house can be done in late June or early July. Seedlings should be planted at 3 to 4-inch intervals in rows 6 inches apart, and the soil should contain a large amount of peat moss to insure the necessary acidity. Watering and weeding should be done as needed, but cultivation should be stopped at least a month before the first frost to allow the plants to mature. Seedlings should be protected during the winter by heavy mulching or sash if they are in suitable frames. Two- and three-year-old

stock should be used for field plantings (*Laurie and Chadwick 1931:142*).

From late spring to midsummer, mountain-laurel may be propagated by layering. Lateral branches of established plants are bent to the ground, pegged in place, and covered with soil. Roots develop where the branch is in the soil. Layered stems should be watered in dry seasons and occasionally checked for roots. Most layered branches form good roots in 1½ years. When firmly rooted, the layered stem should be severed from the parent plant, but left in place for another year before transplanting (*Laurie and Chadwick 1931*).

No reference was found to direct-seeding in the field, but the method should work where the seedbed and soil are suitable. Layering could be used to increase the size or density of existing laurel stands.

MANAGEMENT

Because of its esthetic appeal, mountain-laurel is often encouraged along roadways, and in parks or other areas where scenery is important. It can be used as an ornamental on most acid sites and makes an excellent natural screen. Many kinds of wildlife find cover in laurel thickets, and where other low evergreen cover is lacking, some laurel should be preserved. Stands can be rejuvenated by removing overtopping trees and cutting laurel stems to cause sprouting. Laurel thickets are often so dense and large that they interfere with timber regeneration and other forest uses (*Wahlenberg and Doolittle 1950, Chapman 1950*).

Planting with white pine has been recommended for converting Southern Appalachian laurel thickets to timber production (*Minkler 1941, Wahlenberg and Doolittle 1950*). Planting can be done most economically in the numerous openings left by tractor logging. Timber should be harvested in winter, and seedlings planted in early spring of the same year. Where trees are absent, site conversion requires hand clearing or bulldozing before planting.

Spraying with 2,4,5-T has been effective for eliminating small clumps of laurel, but costs too much for extensive treatment. A basal spray of 2,4,5-T in oil (20 pounds acid equiva-

lent per 100 gallons) gave 89 percent crown kill and excellent sprout control. Sprouting

was also controlled on laurel stumps sprayed with 2,4,5-T (*Sluder 1958*).



RED MULBERRY

Morus rubra L.

By Earl L. Core

West Virginia University
Morgantown

RANGE

Red mulberry occurs from Vermont and Massachusetts to New York, extreme southern Ontario, southern Michigan and Wisconsin, southeastern Minnesota and southeastern Nebraska, south to central Kansas, western Oklahoma, and central Texas, and east to southern Florida.

There is evidence that red mulberry, once common, is vanishing from at least a portion of this range, possibly because of a bacterial disease. Mature fruiting trees are now scarce in many areas (Affeltranger 1965, Core 1966: 75). Its place is often being taken by the introduced and escaped white mulberry (*M. alba*), which may be confused with red mulberry because its fruits, typically white at maturity, may be pink or pale purple to nearly black (Strausbaugh and Core 1952-64).

HABITAT

Red mulberry grows under a wide variety of climatic conditions, from the northern forests of New England to the warm regions of the Gulf Coast and the subtropical forests of Florida. Rich soil of flood-plain forests seems best for the growth of red mulberry. A pH range of 6.0 to 7.5 has been reported as optimum (Spurway 1941).

Towards the south, common species associated with red mulberry include sycamore, American elm, silver maple, and sweetgum.

Northwards it is associated with American elm, red maple, boxelder, and white ash.

LIFE HISTORY

Male and female flowers are usually borne on separate trees, but sometimes they may occur on the same tree. Pollen is carried by the wind in April and May. The fruit, somewhat resembling an elongate blackberry, is composed of numerous juicy drupelets formed from separate female flowers ripening together in July. The entire fruit is 0.5 to 1.5 inches long, dark red in color, and quite sweet.

The minimum commercial seed-bearing age is reported as 10 years, the optimum 30 to 85, and the maximum 125 years. The seeds are minute, with thin membranous coats. A variety of song birds and mammals disperse the seeds, and seed has apparently been the primary source of new stands of red mulberry (Fordham 1967). There is little evidence of reproduction by sprouting or other vegetative means. In original forest conditions, red mulberry apparently made good growth in shade, but in many areas where the trees were once common, seedlings are no longer found.

USE BY WILDLIFE

At the season of ripening, red mulberry fruits are among the most popular foods of songbirds. The trees attract large numbers of birds, which do not even wait until the fruits are ripe before they start eating them.

Birds listed as important feeders are cardinal, catbird, crow, Baltimore oriole, starling, brown thrasher, wood thrush, cedar waxwing, and red-headed woodpecker. Birds having mulberry fruits as a somewhat lesser proportion of their diet are crested flycatcher, purple grackle, rose-breasted grosbeak, northern blue jay, kingbird, robin, English sparrow, scarlet tanager, and tufted titmouse. Opossums, raccoons, fox squirrels, and eastern gray squirrels also eat mulberries in appreciable amounts; and cottontail rabbits feed on the bark in winter (Martin et al 1951, Trippensee 1938). Red mulberry has little or no value as cover for wildlife.

PROPAGATION

Ripe mulberry fruits may be collected by shaking them from the trees onto a tarpaulin. The berries are mashed and soaked in water for 24 hours, then run through a macerator, floating off the pulp. About 2 to 3 pounds of seed are yielded by 100 pounds of fruit. Number of cleaned seeds per pound range from a low of 200,000 to a high of 500,000, with an average count of 360,000 (U. S. Forest Service 1948). It is recommended that the seed be stored dry in sealed containers at 41°F (U.S. Forest Service 1948).

The best natural seedbed is a moist, rich, loamy soil, at least partially protected by litter or vegetation. Germination begins in the spring. Laboratory tests show that the germination rate is poor. Stratification in moist sand for 90 to 120 days at 41°F helps to overcome the dormancy. Mulberry seed mixed with sand or sawdust may be sown in drills in October or November, or seed that has been stratified may be sown in the spring and covered with one-fourth inch of soil. Good results are secured from drills 8 to 12 inches apart, using about 50 seeds to the linear foot of row.

Fall-sown beds should be mulched with straw or leaves and protected by shade screens until germination begins in spring. Spring-sown beds should be mulched with burlap and kept moist until germination begins. Seedbeds should be given partial shade for a few weeks after germination begins. Germination usually takes place 1 to 2 weeks after spring sowing (U. S. Forest Service 1948). Seedlings should

be hardened off to prevent frost injury (Munns 1938). Seeds are reported as germinating rapidly at alternating temperatures of 68 to 86°F in light without any pre-chill treatment (Heit 1968). One-year-old seedling stock is used for field planting.

Red mulberry can be propagated from stem cuttings or by budding, but both methods are complex and require a greenhouse (Halls and Alcaniz 1965a, Munns 1938). Stem cuttings taken in May, September, and January and treated with indole-butyric acid had an average of 7 percent developing roots regardless of time of year (Halls and Alcaniz 1965a).

MANAGEMENT

Some birdwatchers say that if they could choose only one fruiting tree to attract birds, they would select the mulberry. Although it is a desirable plant in bird sanctuaries, parks, and campgrounds, red mulberry is not recommended for general wildlife plantings. It has relatively little value as wildlife cover or for soil conservation.

In planting trials, survival has been consistently very poor. Of seven plantings made from New York to West Virginia, none had more than a few scattered plants remaining after 5 to 8 years. The few plants that lived made fair to good growth, ranging from 5 to 18 feet; but none fruited (Edminster and May 1951).

Red mulberry stands of any size are not mentioned in the literature, and the species is becoming scarce in many areas, perhaps because of disease. *Pseudomonas mori* is reported as causing a moderately severe disease, manifested chiefly as a leaf spot and blight (Pearce and Spaulding 1942). *Mycosphaerella mori*, the cause of leaf spot in red mulberry, is widespread and abundant. Mulberry is also attacked by the Texas root rot caused by *Phytophthora omnivorum* (Van Dersal 1938). The cerambycid borer *Dorcaschema wildii* is a destructive insect pest southwards (Solomon 1968).

Fenuron has been used as a herbicide to control weeds in mulberry seedbeds.

Mature mulberry trees have been used for lumber, and the timber is especially good for lathe work.

BEAR OAK

Quercus ilicifolia Wangenh.

Also called Bitter-Bush, Bitter Oak, Black Scrub-Oak, Dwarf, Black Oak, Holly Oak, Jack Oak, Red Brush, Scrub Oak, Turkey Oak.

By Leonard J. Wolgast

Rutgers University
The State University of New Jersey
New Brunswick

RANGE

This species occurs from southern Maine to New York and Pennsylvania, south to West Virginia, western North Carolina, and Virginia (Little 1953).

HABITAT

Bear oak occurs on acid, rocky or sandy, sterile soils, especially on dry sandy barrens and rocky hillsides. It is found at elevations ranging from sea level to about 3,000 feet (Society of American Foresters 1967). A soil pH of 4.5 to 6.0 is optimum for the growth of bear oak, and a pH of 7.5 is the maximum it will tolerate (Spurway 1941). Bear oak has been observed to remain healthy and produce acorns on soils having a pH as low as 3.8, and acorn production was not related to soil acidities between pH 3.8 and 4.6 on New Jersey's outer Coastal Plain (Wolgast 1972).

The conifers associated with bear oak include these pines: Virginia, pitch, white, table-mountain, and shortleaf. Hardwood associates include chinkapin, scarlet oak, black oak, northern red oak, chestnut oak, dwarf

chinkapin oak, black locust, red maple, sassafras, and blackgum (Society of American Foresters 1967). The chief upland shrubs associated with bear oak in the pine region of New Jersey are huckleberries and lowbush blueberries; sweetfern and hawthorn are less common associates (Little et al 1958). Mountain-laurel is usually the most common shrub associate at higher elevations.

LIFE HISTORY

The male flowers are borne in thin drooping aments, 1½ to 3 inches long. These occur on the growth of the preceding season or from the axils of the scales of the terminal buds. The female flowers, which occur on the same tree, are borne in the leaf axils of the current season. Flowering occurs in April, May, and June, when the leaves are approximately one-fourth to one-half grown. Wind spreads the pollen; and the fruit, an acorn, ripens during September and October of the following year (Brown 1938).

Some specimens planted for wildlife in New York and Pennsylvania produced acorns by the eighth year (Edminster and May 1951).

Three-year-old sprouts have been observed bearing acorns in New Jersey, and 24-year-old trees have also continued producing acorns. Acorn production is highest in stands of even-aged sprouts ranging in age from 5 to 8 years. Beyond 8 years of age, acorn yields begin to decline (*Wolgast 1972*).

Although this species is considered to be a prolific bearer (*Brown 1938*), acorn crops are highly variable. Two climatic factors that contribute significantly to this variability are high relative humidity at the time of flowering, and late-spring frosts. Some trees are inherently good producers of acorns while others are inherently poor producers (*Wolgast 1972*).

Seed is spread by birds, mammals, and gravity; but the distance of spreading is not definitely known.

Bear oaks reproduce from seeds or by sprouting from the root collar. After a rapid initial period of growth to a height of 4 to 5 feet, height growth occurs at the approximate rate of 1 foot every 4 years on New Jersey's outer Coastal Plain. This growth rate may vary considerably from site to site and has not been studied beyond the age of 24 years (*Wolgast 1972*).

Bear oak grows best in full sunlight. It readily invades openings created by clearcutting or fire. It will persist in the understory of a pine stand, but studies on New Jersey's outer Coastal Plain indicate that acorn production is lower on trees growing in shade (*Little et al 1958*).

USE BY WILDLIFE

Turkeys, grouse, quail, squirrels, deer, and bear feed extensively on bear oak acorns. Deer also browse on the foliage and twigs. The acorns are also utilized by many smaller birds, particularly jays and woodpeckers. The small size of the acorns makes them readily swallowed (*Edminster 1947; Martin et al 1951; Van Dersal 1938*).

Bear oak often grows in thickets, which provide excellent cover for many wildlife species during all seasons.

The ability of bear oak to grow on exposed sites makes it valuable as a cover tree, protecting the site until other species can get started (*Brown 1938*).

PROPAGATION

Seed or stock is not available commercially. However, seed can be harvested in September and October from existing stands. The seed may be removed from the cup, or the entire acorn may be planted. One hundred pounds of acorns may be expected to yield approximately 75 pounds of clean seeds, and 1 pound of clean seed contains 500 to 700 seeds (*Edminster 1947*). The Eastern Tree Seed Laboratory reported in 1970 (*Darrell Benson, personal communication*) that maximum germination response (95 percent) and good germination speed was obtained after 90 days of stratification at 38°F. This confirmed an earlier report that up to 95 percent germination may be expected in bear oak (*Edminster 1947*).

Optimum seed storage conditions for bear oak are unknown, but dry storage in sealed containers at temperatures of 32 to 36°F is successful for other oaks. Over-winter storage may also be accomplished in well-drained outdoor pits below the frost line.

Stratified seeds may be sown in the spring, or fresh seeds may be sown directly in the fall at the rate of 10 acorns per square foot or 2 pounds per 100 square feet. The beds should be covered with 1 inch of firmly packed soil and a mulch of straw or leaves. Covering the beds with hardware cloth holds the mulch in place and protects against rodents. The mulch should be removed when danger of frost is over in the spring, and the soil should be kept moist until germination is complete (*U. S. Forest Service 1948*).

Direct fall seeding in the field may be more desirable than the planting of nursery stock except where risk of acorn loss to rodents is high. In areas where it is desirable to use nursery stock, 1-0 seedlings are satisfactory (*U. S. Forest Service 1948*).

MANAGEMENT

Burning, cutting, and routing increased sprouting by bear oak. Single-stem plants so treated may produce up to 40 or more new stems (*Worley et al 1957*).

Since bear oak grows on infertile areas

where food is often the factor limiting wildlife, management should include treatments to increase acorn production. In New Jersey the mid-March application of 800 pounds per acre of 5-10-5 fertilizer resulted in a significant increase in the acorn crop; sprouts that were more than 8 years old exhibited a significantly greater response to fertilizer than younger sprouts. Bear oaks fertilized at this same rate also produced significantly greater quantities of browse at all ages (*Wolgast 1972*).

Bear oak is difficult to control because of its sprouting habit, but some success has been attained by using 2,4,5-T esters in oil as a basal spray. Optimum top-kill was obtained by carefully and completely encircling the basal portion of the stems with 2,4,5-T esters in oil at a minimum concentration of 2 percent by volume. To avoid resprouting, the treating solution must cover the root collar of the plant. Early winter treatments were most successful (*Worley et al 1957*).

PARTRIDGEBERRY

Mitchella repens L.

Also called Checkerberry, Creeping Chequer Berry, Deer Berry, Hive Vine, One Berry, Pain de Perdrix, Running Box, Squawberry, Squaw Vine, Twinberry, Two-Eyed Berry, Two-Eyed Chequer Berry, and Winter Clover.

By Charles M. Nixon

*Ohio Department of Natural
Resources
New Marshfield*

and

D. Michael Worley

*Ohio University
Athens*

RANGE

Partridgeberry occurs from southwestern Newfoundland, southern Quebec, Ontario and Minnesota south to Florida and Texas (Fernald 1950).

HABITAT

Partridgeberry is acclimated to nearly all the extremes of climate in the Northeast, but is generally confined to mildly acid soils (pH 4.5 to 6.0) with a high organic content (Laurie and Chadwick 1931). The optimum pH range was reported as 5.0 to 6.0 (Spurway 1941). If moisture is present, partridgeberry even grows in shallow leaf mulches on rock substrates. It is found in both moist and dry situations; but in the southern portions of the region, at lower elevations, it is usually found in coves or lower north and east-facing slopes (Braun 1950).

In the hemlock-white pine-northern hardwood community, partridgeberry is closely associated with hemlock. Understory associates include bunchberry, hard and soft maples, beech, birches, hobblebush, and beaked hazel.

In the hemlock-mixed mesophytic forest, partridgeberry is often dependent on hemlock leaf mold, but is also found in the beech-maple and mixed hardwood communities transitional to oak chestnut. In the oak-chestnut forest featuring mixed oak and hemlock, partridgeberry is usually found beneath hemlock or rhododendron understories (Braun 1950).

LIFE HISTORY

To insure cross-pollination, flowers of partridgeberry are of two kinds (styles and stamens differ) and are joined in pairs, either terminal or axillary. Flowering occurs from May to July, and the blossoms are white, often fringed with purple. Fruits turn scarlet as they ripen in August and September, and often persist throughout winter (Braun 1961). The fruit is a twin drupe with eight nutlets, formed by fusion of the paired flowers. Seeds are usually spread through ingestion by birds and mammals.

Partridgeberry is not a prolific seeder. In southeastern Ohio, we examined mats of partridgeberry for mature fruit in early October. Ten mats totaling 369 square feet averaged

only 0.51 fruits per square foot (range 0.12 to 0.75).

Twelve pounds of clean seed was obtained from 100 pounds of fruit, and there were 198,400 seeds per pound of seed (*Swingle 1939*).

Partridgeberry reproduces by seed and by stem-rooting at the leaf nodes. Stems grow along the ground, forming dense mats with individual stems 4 to 12 inches long (*Gleason 1963c*). The growth rate per stem has not been reported.

Partridgeberry is very shade-tolerant. The mat-type growth and the heavily shaded habitat favored by partridgeberry tend to discourage competition by herbaceous plants (*Braun 1950*).

USE BY WILDLIFE

The fruits are eaten by ruffed grouse, bobwhite quail, wild turkey, spruce grouse, red fox, skunks, white-footed mice, raccoons, opossums, and squirrels in fall and winter (*Goodrum 1940, Korschgen 1967, Martin et al 1951, Van Dersal 1938*). Partridgeberry was reported as one of the 25 most important foods of the ruffed grouse in the Northeast by Edminster (1947). The fruits were eaten by grouse during the fall and winter while the leaves were eaten rather consistently year-round. Partridgeberry stems and leaves made up a small portion of the winter diet of deer in Massachusetts (*Hosley and Ziebarth 1935*) and were eaten in small quantity during spring, fall, and winter by deer in Ohio (*Nixon et al 1970*). Partridgeberry has little or no cover value.

PROPAGATION

Seed is not usually available commercially, but rooted cuttings can be obtained from wild-plant nurseries. Seeds should be collected

in the fall and sown either in late winter or spring. Stem cuttings may be taken in spring or fall. Root divisions should be made in the spring (*Laurie and Chadwick 1931*).

In the nursery, seeds may be sown during January or February, in a peat-soil-sand mixture, and lightly covered with peat. Seeds will usually germinate in 2 to 3 weeks if the soil is kept moist and at 60 to 65°F. In about 3 months, plants are large enough for transplanting into flats. Temperatures should remain below 60°F for best growth (*Laurie and Chadwick 1931*).

Under greenhouse conditions, stem cuttings produced roots in 4 to 6 weeks at a temperature of 40 to 45°F (*Laurie and Chadwick 1931*).

No information is available about direct-seeding of partridgeberry. Spring transplanting of either rooted cuttings or root divisions would seem to provide the most rapid method of establishment. Transplants should be made on mildly acid soils in shaded sites, preferably under hemlock. Either moist or dry situations are acceptable, but soils should be high in organic matter.

MANAGEMENT

Once established, partridgeberry grows best in shade. Ordinarily the overstory trees, particularly hemlock, should not be removed because competition in cut-over stands may reduce or eliminate partridgeberry, at least until shade is reestablished. Light commercial thinning or weeding, using single tree selection, seem best for maintaining mats of partridgeberry (*Edminster 1947*). In certain communities, hemlock is necessary for maintenance.

Although specific control recommendations were not found, herbicide treatment such as 2,4-D or 2,4,5-T applied as a foliage spray in midseason should control partridgeberry. Such control is seldom necessary.

RHODODENDRON

Rhododendron maximum L.

Also called Great Laurel, Rosebay, Rosebay Rhododendron, and White Laurel.

By Sadie L. Robinette

West Virginia University
Morgantown

RANGE

Rhododendron grows from southwestern Maine to Vermont, New York, and extreme southern Ontario to Ohio and Pennsylvania, south in mountains to eastern Tennessee, northern Alabama, northern Georgia, western South Carolina, and western North Carolina (Little 1953).

HABITAT

Rhododendron grows on acid soils, usually within the pH range of 4.5 to 5.5 (Kellogg 1952, Leach 1961). In the northern part of its range, rhododendron occurs in isolated colonies in deep, cold swamps. It is abundant along the mountain streams in western Pennsylvania, and becomes common farther south, occupying steep stream banks up to altitudes of 4,500 feet (Cox and Cox 1956). It reaches its largest size and grows most profusely in the southern Appalachians, where it often forms thickets many acres in size (Sargent 1922).

Rhododendron and eastern hemlock (*Tsuga canadensis*) have similar ranges and site preferences (Hodgdon and Pike 1961), and in most areas they are closely associated (Braun 1950). In New England and southeastern

Canada, rhododendron occurs locally in bogs and in bog borders beneath hemlock-white pine or hemlock-beech stands. In the Catskill and Allegheny mountains it is frequently the only understory beneath hemlock stands along streams, and it is also a dominant shrub in shady, moist ravines in the ridge and valley area of Pennsylvania, West Virginia, and Maryland.

LIFE HISTORY

The large pink or white flowers bloom from June in the south to August in the northern part of our region. Insects pollinate the flowers. The fruit is an oblong capsule, which turns greenish brown when ripe. Seeds are less than 1/32 inch long, brown, and tufted at each end. Each capsule contains 300 to 400 seeds (Romancier 1969), and there are 5,000,000 to 5,700,000 seeds per pound (U. S. Forest Service 1948). Ripe capsules split along five lines to release the seeds, and wind disperses them for short distances (Bailey 1916).

Rhododendron reproduces from seeds, sprouts, layers, and suckers; but seeding and layering are the principal means of regeneration for natural stands. Disturbances such as

cutting or burning usually result in vigorous regeneration from stump sprouts, root suckers, and sprouts from layered stems (Yawney 1962).

Rhododendron is moderately shade-tolerant; seed germination is best under partial shade (U. S. Forest Service 1948). Sprouting perpetuates rhododendron thickets, but its own seedlings are seldom found within the perimeter of a given thicket (Robert Romancier, personal communication). Rate of growth depends on the nature of the site. In Georgia and North Carolina, rhododendron thickets were 8 feet tall when 15 years old, and 11 feet tall when 26 years old. Sprouts that developed after cutting these stems to the ground grew 4 feet tall in 6 years (Wahlenberg and Doolittle 1950). The range in average age for eight rhododendron stands in North Carolina was 48.6 to 61.4 years (Smith 1963). Individual stems commonly reach 70 years of age, but none over 85 years old was found (Romancier, personal communication).

USE BY WILDLIFE

Rhododendron is valuable as winter and escape cover for white-tailed deer, eastern cottontail, black bear, snowshoe hare, ruffed grouse, wild turkey, and many songbirds. Rhododendron is heavily browsed by deer during the winter in Pennsylvania and West Virginia (DeGarmo and Gill 1958, Latham 1950). Ruffed grouse take leaves, buds, twigs, and seeds (Edminster 1947). Leaves are eaten by several small mammals, including the white-footed mouse and Allegheny wood rat (Martin et al 1951).

PROPAGATION

Rhododendron seed is available from Forestry Associates, PO Box 1969, Allentown, Pennsylvania; or capsules may be collected from wild plants from October through January. After air-drying, capsules can be rubbed or beaten if they have not already split open, and the seeds can be shaken out.

Seeding, layering and cutting are the major means of propagating rhododendron. The method used depends on the objective; vegetative means are needed to preserve genetic

traits. Attempts to establish rhododendron should be limited to acid soils with a high content of organic matter and ample soil moisture at all times (Hottes 1931, U. S. Forest Service 1948).

Following standard nursery and greenhouse propagation techniques (Bowers 1960, Laurie and Chadwick 1931), seed should be air-dried and stored in sealed containers after removal from the capsule. Seed may be kept at room temperature if it will be used in a month or two; but for longer storage, seed should be refrigerated at 40 to 50°F.

The seed should be planted in the greenhouse in January or February. Wooden flats or any small container that allows good drainage can be used for planting. The soil mixture should be acid in reaction and porous. A good planting mixture can be made from decayed oak litter, sand (about 25 percent by volume), and a small amount of peat moss. The soil should be firmed in the flats and covered approximately $\frac{1}{4}$ inch deep with ground sphagnum. The seeds should be broadcast directly on top of the sphagnum, and partially covered with a very light additional coating of ground sphagnum.

The soil should be thoroughly watered at planting time. The temperature should be kept at 60°F at night and from 65 to 70°F during the day; lower temperatures delay germination. At these temperatures the seeds require 16 to 20 days for germination, and an average germination of 85 percent can be expected (Romancier, personal communication). Seedbeds should be kept well watered after germination. At age 3 months, or as soon as the first true leaves appear, the seedlings should be separated carefully and planted at least $1\frac{1}{2}$ inches apart in flats containing the soil mixture used for planting. Partial shade is necessary, and temperatures should be kept near 60°F, which is relatively cooler than optimum temperature for germination.

Seedlings may be carried through the first summer outdoors or in the greenhouse. Keeping plants in the greenhouse often requires two or three additional transplantings, plus careful attention to shading and watering. It is best to place plants outside in a shaded frame or shade house. Seedlings should be

moved outside during late June or early July, and transplanted into rows 6 inches apart with a 3 to 4-inch spacing in the row. The soil should contain a large amount of organic matter such as peat moss to insure the necessary acidity. Seedlings should be watered and weeded regularly; but to allow the plants to mature before winter, watering and cultivation should stop by mid-August.

Rhododendron seedlings left outside during the winter should be protected by heavy mulching or sash if they are in suitable frames. Sash may be covered with straw mats or loose hay if further protection is necessary. Mulching and pest control should be done carefully in the winter. Transplanting to the open field should take place during the third or fourth spring.

Nurserymen commonly use leaf and stem cuttings to propagate rhododendron. A greenhouse is a necessity; and the process is difficult, so it will not be covered.

From late spring to midsummer, rhododendron may be propagated by simple layering, a process in which branches from well-established plants are bent until they touch the ground. The part touching the ground is covered with soil, but the leaves at the tip of the branch are left exposed. Roots will develop along the underside of the branch. In the nursery, layered branches should be watered during dry seasons and checked for roots occasionally. Most branches will form good roots in 1-1/2 years. When adequate roots develop, sever the new plants from the parent, but leave them in place for a year. After this time, plants may be transplanted to new sites.

Layering is generally a nursery practice, but it appears to be a good field technique for increasing the number of plants where some already exist. No reference to direct-seeding in the field was found, but in nurseries, sowing seeds outside during April has been successful. Seedbeds were prepared the same way as in the greenhouse.

MANAGEMENT

Rhododendron is an excellent ornamental; and once established, it requires little maintenance. Rhododendron's dense growth form and evergreen leaves make it well suited for use as a natural screen. The variety of landscaping uses for the plant is limited only by its soil requirements and the manager's imagination. Natural stands provide protection for watersheds and cover for wildlife. In areas where rhododendron is the principal evergreen cover, some consideration for its preservation should be included in management plans. Rhododendron sprouts rapidly after injury, and cutting is an excellent method for rejuvenating stands.

Extensive stands of rhododendron, common in the southern Appalachians, may present control problems (Wahlenberg 1950). Thickets reach their best development on better sites, where they often prevent natural regeneration of timber trees and may interfere with other forest uses. Planting with white pine has been recommended for converting southern Appalachian rhododendron thickets to timber production (Minckler 1941, Wahlenberg and Doolittle 1950). Planting can be done most economically in openings left by tractor logging. Timber should be harvested in winter, and seedlings planted in early spring of the same year. Where timber trees are absent, site conversion requires hand-clearing or bulldozing before planting.

The following rhododendron control treatment was used at the Fernow Experimental Forest in northern West Virginia. A 20-pound acid equivalent per 100 gallons mixture of 2,4,5-T in diesel oil was applied by a hand sprayer to stem cuttings or stumps, and as a basal spray. Rhododendrons were killed by both treatments, but high cost made these methods suitable only for eliminating scattered clumps (Yawney 1962).

In a study conducted on the Bent Creek Forest near Asheville, North Carolina, treating stumps with 2,4,5-T gave good sprout control (Sluder 1958). Good top kill was obtained with sodium arsenite, but sprouting was heavy; and the chemical is highly toxic to man and other animals (Sluder 1961).

ROSES

CAROLINA ROSE, *Rosa carolina* L. Also called Low, Pasture, or Wild Rose.

JAPANESE ROSE, *Rosa multiflora* Thunb. Also called Bramble, Multiflora Rose, or Rambler.

SWAMP ROSE, *Rosa palustris* Marsh.

PRAIRIE ROSE, *Rosa setigera* Michx. Also called Climbing or Michigan Rose.

VIRGINIA ROSE, *Rosa virginiana* Mill. Also called St. Mark's Rose.

By Margaret Smithberg

*University of Minnesota
St. Paul*

and

John D. Gill

*Northeastern Forest
Experiment Station
Morgantown*

RANGE

All five species occur throughout the Northeast south of a line from southern New England to Michigan. Three species also range northward into Canada:

Carolina rose—Nova Scotia, southwestern Maine to southern Ontario, Minnesota.

Swamp rose—Nova Scotia, southern Quebec to Minnesota.

Virginia rose—Newfoundland, Nova Scotia to southern Ontario.

Roses hybridize freely and it is often difficult to distinguish them, especially where their ranges coincide (Grimm 1952). Carolina rose is the most widely distributed rose in eastern North America, and is quite variable. Virginia rose is the most common rose in New England, but in the southern limits of its range it may be confused with Carolina rose.

Swamp rose is found in practically all states east of the Mississippi River, but is often confused with Carolina rose; however, swamp rose is more common in moist situations. Prairie rose is most common in Ohio and the central Mississippi Valley, and is sparse elsewhere. It has escaped from cultivation in the eastern part of its range.

Although Japanese rose is not a native, having been imported from Japan and Korea in 1875 (Shepherd 1954), it has escaped from cultivation and is commonly found growing in the wild. It is included in this report because it has been used more in conservation work than any other rose species.

HABITAT

In cultivation, clay-loam soils are most commonly preferred for roses; but in the wild, roses occupy many different kinds of soils

(Shepherd 1954). Most species thrive on moderately fertile, well-drained, clay-loam, sandy loam, or sandy soils (Hosely 1938). And most are relatively insensitive to soil reactions, at least within the circumneutral pH range (Wherry 1957).

Carolina rose is often found on dry, sandy, or rocky soils (Grimm 1952) and may prefer moderately acid conditions. Swamp rose, of course, grows well on wet soils, and they usually are at least moderately acid. However, the optimum soil reaction was reported as pH 6.0 to 8.0 (Spurway 1941). Prairie rose grows best on the better loam soils (Hosely 1938). Virginia rose tolerates a wide range of soil and moisture conditions. It thrives in sandy soils (Zucker 1966), and is common in dry uplands in Ohio (Chapman 1947c). But it has also been recommended for planting in heavy clay soil (Hottes 1937). Optimum pH was reported as 6.0 to 8.0 (Spurway 1941).

Japanese rose probably requires higher soil fertility than any of the native species. It has been recommended for practically all soils except those that are poorly drained (Edminster 1947), but grew poorly on infertile acid soils in New York (Smith 1964) and was recommended primarily for "good" loams and loamy sands in Michigan (Zorb 1966). Japanese rose was not adapted to the poorer sites on strip-mined land in Ohio and did not compete successfully in established meadows (Riley 1957), but has been recommended for some mine spoils with soil reactions of pH 5.0 or higher (Joseph Ruffner, unpublished report). In the Southeast, Japanese rose is often found on moderately fertile clay soils (Rosene 1950).

Although the roses occupy many kinds of soils, they are restricted mainly to open sites because they are intolerant of shading. Carolina rose has been given a qualified endorsement for landscape use in shaded locations (Kammerer 1934), but full sunlight exposure is best for all species. In the open, most species spread easily and often dominate the plant community.

Carolina rose is common on roadsides, in fence rows, woods borders, and thickets (Grimm 1952), and is often dominant on dunes and prairies (Gleason 1963b). Japanese

rose escapes readily from gardens and fence rows and becomes common in fields, woods borders, hardwood stands, and thickets—wherever birds deposit the seed. In the Southeast it is common in loblolly pine woodlands, but in mixed stands is often spindly (Rosene 1950). Swamp rose is commonly found with willows, red-osier dogwood, and other wetland species. Prairie rose grows in open situations such as thickets, fence rows, roadsides, and woods clearings. It often climbs into trees or reclines on shrubs or fences (Hottes 1937). In the Midwest, it is common in fields, pastures, and roadsides.

LIFE HISTORY

The roses generally are capable of flowering and fruiting at 2 years of age (Spinner and Ostrom 1945) but fruiting may not occur until the third or fourth year. The flower is pollinated by insects and develops into a red, fleshy, berry-like hip. Typically, the hip encloses several small, bony seeds (achenes), ripens in late summer and early fall, and persists on the plant until winter or later—for about 200 days in the Japanese rose (Gysel and Lemmien 1955).

Natural establishment of new plants is largely from seeds spread by birds or mammals. Digestion of rose fruits by pheasants and sharp-tailed grouse reduced total germinability but increased germination of those achenes which passed through the birds without harm (Krefting and Roe 1949).

Once established, most roses spread by suckering from roots and undergrown stems or by layering. Japanese rose spreads very aggressively on good sites, and may become a serious pest. Growth forms of the roses discussed here are:

Carolina—low, upright shrub.

Japanese—tall; upright to reclining, occasionally climbing; forms dense spiny thickets.

Swamp—medium height, upright, thicket-forming shrub with slender stems.

Prairie—low sprawling or climbing viney shrub with long weak canes.

Virginia—medium height, upright shrub.

Table 1—Roses: growth, flowering, and vegetative reproduction.

Species	Height, feet	Cane length, feet	Flowering dates	Flower color	Spreads by—
Carolina	3-4	—	June-July	Pink	Stolons
Japanese	6-10*	6+	June-July	White	Layers
Swamp	6	to 16	June-Aug.	Pink	Rhizomes
Prairie	1+*	6-18	June-Aug.	Rose to white	—
Virginia	6	—	June-July	White	Stolons, few

*Height varies because Japanese rose occasionally climbs, and prairie rose often does.

Other details of growth, flowering, and vegetative reproduction are in table 1.

All roses grow more vigorously and produce more fruit when growing in full sunlight than when in shade, but Carolina rose may be slightly more shade-tolerant than any of the other four species. Japanese rose plants attain their full height growth in about 5 years (*Edminster and May 1951*). Growth rates for the other species are unknown.

In the wild, roses are relatively free from insect and disease attacks. Japanese rose may be damaged by Japanese beetles, other insects, leaf spot, and crown gall; but no serious injury was noted by Edminster and May (1951). Prairie rose plants growing near the northern limits of the species range may be winter-killed to ground level (*Zucker 1966*).

USES

According to Van Dersal (1938), some reports of the species of roses used by wildlife may be misleading. Accordingly, most of the discussion presented here is for the genus rather than for individual species.

The fruit and other parts of rose plants are eaten by many mammals, especially hoofed browsers. Some roses can withstand browsing that removes nearly two-thirds of the annual growth in spring and summer (*Young and Payne 1948*). Mountain sheep, chipmunks, deer, opossum, and coyote browse on the leaves and fruit (*Van Dersal 1938*), as do bear, beaver, rabbit, snowshoe hare, skunk, mice, antelope, deer, and elk (*Martin et al 1951*). Rose is a preferred food of deer in Kentucky (*Barber 1962*) and Idaho (*Thilenius*

1960). Five years after soil in an area in Western Alberta was scarified, roses provided abundant browse for deer and elk (*Stelfox 1962*).

Japanese rose has been in use in the United States for over 25 years, and its chief value has been for wildlife cover and food (*Dugan 1960*). Its value for wildlife has been shown repeatedly as, for example, in an 8-year study of food-producing plants in Michigan; Japanese rose received more use by wildlife than any other plant (*Gysel and Lemmien 1964*). However, use has been curtailed in many states because of serious problems in controlling spread of Japanese rose.

Roses are important to wildlife because the fruits remain on all winter, when most other fruits are gone or covered by snow. Ruffed grouse, bobwhite, sharp-tailed grouse, prairie chicken, and wild turkey feed on the fruits (*Van Dersal 1938*). Ruffed grouse feed on roses mostly from October through March in the Northeast; and rose hips, plus some leaves, are among the 25 most important foods (*Edminster 1947*). The hips are a favorite food of pheasants (*Nelson et al 1966*) and turkeys in Indiana (*Schorger 1966*), and the seeds function as grit for grouse and other species. At least 38 species of birds include rose hips in their diet (*Van Dersal 1938*).

Japanese rose provides both food and cover for prairie chickens. The hips were a winter staple for bobwhites but ranked low in nutritional quality as an emergency food (*Newlon et al 1964*). As ruffed grouse food in Missouri, Japanese rose ranked sixth by volume but was heavily used where present (*Korschgen 1966*). Robins and cedar waxwings feed heavily on Japanese rose, which accounts in part for its

rapid spread (*Scott 1965*). Mockingbirds eat Japanese rose all winter; and it is also taken as winter emergency food by song birds, bobwhites, and pheasants (*Davison and Grizzell 1961*).

Roses may be as important for wildlife cover as they are for winter food; the thicket-forming species are excellent as nesting and protective cover for game and song birds (*Chapman 1947c; Martin et al 1951*). For example, in a study in Maryland, the most effective habitat-improvement measure was planting Japanese rose hedges adjoining pastures or with an herbaceous border (*Burger and Linduska 1967*). Cover formed within 2 or 3 years after planting, and the winter and nesting cover provided by the hedges was considered more important than the food. Elsewhere, Japanese rose provided good winter cover for bobwhite and prairie chickens (*Korschgen 1960*); and ruffed grouse roost in rose thickets after heavy snowfalls.

The attractive fall foliage and colorful fruit of roses recommend them for landscaping as well as wildlife-habitat uses. Native roses were ranked excellent as roadside plants in Wisconsin (*Wisconsin Conservation Department 1967*). For general landscaping use, Carolina rose was recommended as a low shrub for dry shady locations (*Kammerer 1934*). Virginia rose is useful as a large hedge plant, and swamp rose is, of course, suitable for wet areas (*Zucker 1966*). Japanese rose (*Buck 1964*), prairie rose, and probably other species, are used as stocks for grafting horticultural varieties of roses. Japanese rose hedges have been recommended as substitutes for fences; after five growing seasons such hedges may confine livestock (*Dale 1956*).

PROPAGATION

Roses can be grown fairly easily from cuttings or seeds, and Japanese rose seed and planting stock are available commercially. Seeds of the other four species discussed here usually cannot be purchased, but seed of other native species with comparable wildlife values is usually available (*Forestry Associates 1970, Northeast Reg. Tech. Serv. Cent. 1971*).

For field collection of seed, the hips can be hand-picked soon after the dark green color

fades into red, or anytime thereafter. Seeds collected shortly after fruit ripening may germinate more readily than those allowed to dry out in the hip (*Shepherd 1945*). Ripening can be speeded up and seed yield increased by wrapping the hips in foil some time before they are to be picked (*Lebedeff 1967*), and this extra effort may be worthwhile if fruit is scarce.

Seeds can be extracted by macerating the hips in water and floating off the pulp and empty fruit (*U. S. Forest Service 1948*), or the hips can be crushed and fermented to remove the seed (*Laurie 1931*). The cleaned seed can be sown immediately, placed in stratification, or air-dried for storage. Some seed lots stored dry in sealed containers at 34 to 38°F have shown excellent germination after 4 to 8 years (*Heit 1967e*).

Data on yield of rose seeds are based on only a few samples. Japanese rose seeds numbered 50,000 to 82,000 per pound of cleaned seed (*Swingle 1939*). The average for swamp rose was 45,000 seeds per pound, and a bushel of fruit yielded 6 to 8 pounds of cleaned seed (*Edminster 1947*). Prairie rose yielded 10 pounds of cleaned seed per bushel of fruit and 50,000 seeds per pound of cleaned seed (*Hugh Stevenson, unpublished data*).

Rose seeds of most species exhibit dormancy, which is due primarily to conditions in the seedcoat rather than in the embryo. Seeds planted without pretreatment may not germinate for 4 months because they contain at least two germination inhibitors (*Fletcher 1960*). Thus germination is prevented until the seedcoat is either weakened by decay or opened chemically or mechanically.

Jackson and Blundell (*1963*) found that dormancy could be broken by treating seeds with gibberellic acid or 6-benzylaminopurine. Davis (*1943*) suggested stratification in damp peat moss in a refrigerator for a few months, then at room temperature until some seeds start to germinate, then at refrigerator temperature again for 6 weeks. Suggested scarification treatments include the rotary file method (*Svejda and Voisey 1962*), and a sulfuric acid bath for 1 to 2 hours (*U. S. Forest Service 1948*). However, Heit (*1967a*) did not recommend sulfuric acid treatment because he

considered the evidence for it to be inconclusive. These special treatments and possibly warm stratification (*Morey 1960*) may be suitable in some circumstances, but ordinary cold stratification will usually be a more practical alternative.

If the seeds are not to be sown immediately, dry storage for as long as needed and stratification at about 40 F for varying numbers of days has been recommended for many rose species. Among the ones discussed here, Japanese rose responded to cold treatment more quickly than Carolina or prairie rose (*Crocker and Barton 1931*), and 28 days at 38 to 41° F may be sufficient for Japanese rose; but a 30- to 60-day period has been recommended (*Heit 1968: pt. 15; Schumacher 1962*). The other species apparently need longer cold treatments: swamp rose 90 to 100 days at 41° F (*Edminster 1947*); and prairie rose 100 days at 32 to 50° F (*Swingle 1939*), or 90 days at 40° F (*Semeniuk et al 1963*). No comparable recommendations for Carolina or Virginia rose were found, but stratification for 90 to 100 days may be adequate; in one study, Carolina rose germinated sooner than prairie rose (*Crocker and Barton 1931*).

The seeds can be stratified in moist peat or vermiculite—the latter gave better results than use of polyethylene bags (*Kozlowski 1960*). *Heit (1968)* recommended testing of commercial seed lots, particularly Japanese rose seeds imported from Japan. Test conditions, following stratification, were: artificial light, 50 to 86° F alternating daily, and 14 to 28 days.

Stratified seed should be sown in early spring (*Schumacher 1962*). Fresh, cleaned seed can be sown in the fall, shortly after ripening, but should not be allowed to dry out before sowing (*Heit 1968*). For swamp rose, *Edminster (1947)* suggested a sowing rate of 6 ounces of seed per 100 square feet, covering the seeds with soil and mulch, and thinning to 25 plants per square foot. He estimated output at 10,000 usable plants per pound of cleaned seed and recommended outplanting of 1-0 stock, or when the plants were about 6 inches tall x $\frac{1}{8}$ inch caliper. Prairie rose output was given as 7,000 usable plants per pound of seed (*Swingle 1939*).

Seedlings started in a greenhouse should be

moved out by the end of May, to avoid overheating (*Morey 1960*). Seedlings can be transplanted to their permanent locations at the end of the first growing season, but if held until 2 years old, they should be top-pruned when outplanted (*Edminster and May 1951*).

Vegetative reproduction is a reasonable alternative to use of seed because nearly all roses propagate easily from cuttings of young wood (*Chapman 1947c*). Hardwood cuttings may be taken in late fall or winter. Basal and terminal cuts are made 6 to 8 inches apart, immediately below and above a node. Remove all buds except the one at the top node (*Adriance 1939*). If the winters are severe, plant the cuttings in cold frames with sand, sandy loam, or in some cases peat or a mixture of peat and sand. If winters are mild, place cuttings directly into nursery rows in the field.

Softwood cuttings, 6 to 7 inches long, may be taken in the spring or early summer. Remove only the basal leaves, plant the cuttings 3 inches deep, shade them until rooted, and water frequently. Gradually remove the shade after 10 to 14 days. Plant in April or May in the South, or in July or August in the North.

According to *Doran (1957)*, among prairie rose softwood cuttings, those with a heel rooted better than those without a heel. Indolebutyric acid (IBA) increased rooting in various roses. Success of summer cuttings of Japanese rose was improved by IBA (2.5 mg per liter for 24 hours, or 2 mg per gram talc). Dormant cuttings of Japanese rose also responded to IBA (5 to 10 mg/liter for 24 hours, or 2 mg/gram in talc). The temperature should be above 60° F.

In the nursery, roses are highly susceptible to diseases, and control is important. The first step in treatment is to prune out the diseased area. Powdery mildew may be treated with the following, all of which were equally effective: Karathane, Acti-dione P.M., folpet spray, or Copper Oleate (*Deep and Bartlett 1961*). *Garrett (1967)* recommended one tablespoon wettable powder of folpet per gallon of water. Spraying is always more effective than dusting.

Blackspot is another serious fungus disease of roses, except that Japanese rose tolerates it (*Buck 1964*). Blackspot can be controlled

with folpet (*Jacklin et al 1966*) or maneb (*Garrett 1967*). And good control was reported for combinations of folpet or Aramite with Santomerse, Tween-20, or DuPont spreader-sticker (*Palmer and Henneberry 1961*).

Control of weeds in the nursery is important to maintain proper growth of rose plants. The herbicides diuron and simazine were recommended (*Schneider 1959*), but dalapon stunted Japanese roses (*Taylorson and Holm 1958*).

MANAGEMENT

Some of the recommendations for establishing Japanese rose (*Edminster and May 1951*, *Zorb 1966*) may apply as well to other roses. Planting locations should be prepared in advance by plowing a double furrow or scalping 1-foot-square spots. Spacing between rows should be about 8 feet, and within rows should be 1 to 2 feet for hedges, 2 to 3 feet for road-banks, and 3 to 4 feet for woods borders. Fertilizer such as 5-10-5 should be applied at about 1 pound per 40 feet of row, and the plants should be side-dressed during the second year with nitrate of soda or equivalent, at the same rate. Machine cultivation is usually not practical for the roses with sprawling growth forms, but weeds can be controlled by spreading granular simazine with a cyclone seeder at about 2 pounds per acre. Apply the herbicide soon after planting the roses and repeat in the second spring.

Although Japanese rose does excellently in open woodland, it has often proved to be an unmanagable pest. It may spread rapidly in idle and unmanaged areas and in unmowable

pastures and fence rows (*Lloyd and Eley 1955*). It often produces a fence 10 to 15 feet wide, difficult to grub out or to pull out with a tractor and chain (*Dickey 1960*). Japanese rose has been reported to reduce the yield of corn by as much as 25 percent in rows next to a hedge (*Labiskey and Anderson 1965*).

To protect the layman, a Japanese rose policy was adopted in 1962 (*Ohio Agricultural Experiment Station 1962*). In essence it was decided not to use the species within 3,000 feet of any of the following: permanent unmanaged pasture; open woods used for timber production; Christmas tree plantings; idle land; and other areas not under management.

Where roses outgrew their bounds they may be difficult to control because all species can regenerate from remnants of their canes (*Fletchall and Talbert 1960*). Spraying with a herbicide may give effective control, particularly with older plants, if spraying is done in the latter half of May or in June (*Oregon Agricultural Progress 1958*). Japanese rose has been controlled with picloram, 2,3,6-TBA, or dicamba (*Scott 1965*), and with Tordon (*picloram*) at the rates of 1 to 3.2 pounds per mile of fence or 0.8 to 2.4 pounds per acre (*Corzart 1965*). In a herbicide manual, Japanese rose was rated susceptible to either monuron or 2,3,6-TBA; and intermediate in susceptibility to either silvex or 2,4,5-T. No comparable information for the other roses discussed here was given. But for several other native species, control was generally better from use of 2,3,6-TBA; monuron; or 2,4,5-T than from 2,4-D; MCPA; simazine; BMM; or silvex (*Dunham 1965*). Some results of applying herbicides by helicopter were reported by Friesen (1961) and Engel (1964).

SASSAFRAS

Sassafras albidum (Nutt.) Nees

Also called Ague Tree, Cinnamon Wood, Common Sassafras, Gumbo File, Mittenleaf, Red Sassafras, Saloop, Sassafac, Saxisfras, Smelling Stick, and White Sassafras.

By Tom S. Hamilton, Jr.

*University of Massachusetts
Amherst*

RANGE

The center of the range is about at the Kentucky-Tennessee border. Edges of the range are southwestern Maine to New York, extreme southern Ontario, central Michigan and Illinois, Missouri, eastern Oklahoma and Texas, and central Florida. Sassafras is no longer found in southwestern Wisconsin, but is extending its range northward within Illinois.

HABITAT

Within the range of sassafras, average annual rainfall is about 30 to 55 inches. Of this, 25 to 30 inches fall during the effective growing season, April through August. At the northern limits of the range, the annual snowfall is 30 to 40 inches, while at the southern limits there may be practically none. The average frost-free period is 160 to 300 days. In January the average temperature is 20°F in the northern part of the range and 55°F in the south; the average July temperatures vary from 70 to 80°F. The altitudinal limit in the southern Appalachians is about 4,000 feet (*U.S. Forest Service 1965*). Sassafras generally

prefers a warm and sunny location in the north and may be killed if not well protected from extremes of winter weather.

Sassafras is found on practically all the soil types in its range, including those that are dry and infertile. However, the best stands are found in open woods on moist, rich, well-drained, sandy loam soils. The optimum soil pH was reported as 6.0 to 7.0 (*Spurway 1941*). On the Lake Michigan dunes of Indiana, sassafras grows on pure shifting sand. It is also found on poor gravelly soil and clay loams.

Sassafras is usually found as scattered individual trees or in small pure stands, and is usually in the dominant overstory. It is also found in the understory along edges of mixed woods, in the open along roadsides, in old fence rows, and in abandoned fields. Scattered trees of the species are found in many forest types such as oak-hickory, oak-pine, cypress-tupelo-sweetgum, and longleaf-loblolly-slash pine.

Common associates include flowering dogwood, elms, eastern red-cedar, American hornbeam, eastern hophornbeam, and pawpaw. In older stands sassafras is also found with ash

and sugar maple. On poorer sites, especially in the Appalachian Mountains, sassafras is also associated with black locust, red maple, and sourwood. At the northern edge of its range it is found in the understory of aspen and pin oak stands (*U. S. Forest Service 1965*).

Sassafras is often a pioneer species on abandoned fields and on dry ridges and upper slopes, especially after fire. It seems destined to continue to increase its range.

LIFE HISTORY

Individual sassafras trees bear either male or female flowers, and the buds of female flowers are much larger than those of males. The flowers bloom in early spring as the leaves start to unfold. Blossoms are greenish yellow, about $\frac{1}{4}$ inch across, and develop in drooping, few-flowered clusters. Fruits ripen in August to October. They are oval, one-seeded, dark blue, spicy drupes $\frac{1}{3}$ to $\frac{1}{2}$ inch long and are borne on erect bright red stems (*U. S. Forest Service 1948, 1965*).

Fruit-bearing begins as the trees approach 10 years of age and is greatest on 25- to 50-year-old trees. On bearing trees, good crops ordinarily occur at 1- or 2-year intervals. But a survey in the Ozarks showed that only 10 percent of the sassafras bore fruit. The proportion bearing was greater on plots in the 20- to 39-percent crown-cover class than in any other class (*Murphy and Ehrenreich 1965*). Fruit crops are usually lighter northward than near the center of the range (*Hosley 1938*).

Fruits collected in Mississippi had an exceptionally high fat content, 47 percent, and contained more total protein than the average among comparable woody plants (*Bonner 1971*). Other studies indicate that seed soundness runs about 35 percent (*U. S. Forest Service 1965*).

Birds are the principal agents of seed dispersal (*U. S. Forest Service 1948*), and some seeds probably are distributed by small mammals. But the effects on seeds of passage through animal digestive tracts are unknown. Seeds that have fallen, without intervention by animals, apparently lose germinability within 2 years. Under simulated natural storage conditions, samples from seeds that were 96 percent sound initially yielded only 12 per-

cent germination after 1 year and none after 2 years (*Clark 1962*).

Sassafras establishes from seed in new areas, but most of the subsequent reproduction is vegetative. The dense thickets often found in woods openings or in old fields are usually from root sprouts. On good sites where competition is not heavy, the sprouts may grow 12 feet tall in 3 years and sometimes are abundant. Where young sassafras is cut, sprouting from the stumps is often prolific (*U. S. Forest Service 1965*).

Sassafras varies in size from shrubs on poor sites, especially in the north and in Florida, to large trees with straight, clear trunks. It may attain heights of 100 feet or more and diameters of 6 feet on the best sites in the southern portions of its range. Most mature trees average 6 to 8 inches dbh. Average height is about 40 feet.

Sassafras in the Northeast has been ranked as intolerant of shade, but in the Southeast may be slightly more tolerant (*Forbes 1955*). It is relatively short-lived and transitory in wooded areas. If it becomes overtapped in mixed stands, it is one of the first species to die, even though it withstands light shade. In the understory along the edges of heavy stands it may persist but generally does not reach merchantable size. In open areas—and especially on abandoned fields—it is an aggressive tree and often is a vigorous invader where conditions are favorable.

USES

The bark, twigs, and leaves of sassafras are important foods for wildlife in some areas. The percentage to which the species may be browsed in several important vegetative types in the north is: cove hardwoods 40, oak-chestnut 40, and pine hardwoods 45 (*Shelford 1963*). Deer browse the twigs in the winter and the leaves and succulent growth during the spring and summer.

Palatability, although variable, is considered good throughout the range. In east Texas, sassafras is highly preferred; in Pennsylvania and western Virginia it is classed as an important source of food. In Ontario it is rated as having medium palatability with heavy browsing. In Arkansas the plants re-

ceive moderate to heavy use during the growing season (*Leonard 1961*). In some areas, sassafras is too palatable to survive long with heavy browsing. Browse users in addition to deer include black bear, beaver, cottontail rabbit, fox squirrel, marsh rabbit, and woodchuck (*Martin et al 1951*).

Sassafras fruit is available from August to October but generally is not an important source of food for wildlife other than bobwhite quail. Some of the other birds that utilize the fruit are wild turkey, catbird, flicker, crested flycatcher, kingbird, mockingbird, eastern phoebe, bluebird, robin, sapsucker, brown thrasher, gray-cheeked thrush, hermit thrush, olive-backed thrush, towhee, red-eyed vireo, warbling vireo, white-eyed vireo, pileated woodpecker, and yellow-throat warbler. Three flycatchers that subsist primarily on insects also eat this fruit. Mammals that eat the fruit include the black bear, raccoon, squirrel, and woodchuck (*Martin et al 1951, Van Dersal 1938*).

In addition to its values for wildlife, sassafras provides wood and bark for a variety of commercial and domestic uses. Sassafras tea is brewed from bark of the roots dug, usually, in the spring. The tea was once thought to be a cure for the ague. For this reason sassafras played an important part in exploration and settlement along the Atlantic Coast during the 16th century. Oil distilled from the bark is used for flavoring or scenting candies, medicines, soaps, and other items; and an extract has been used as an orange dye for wool.

Sassafras is also an attractive ornamental, particularly for use on fairly dry, infertile sites. The fall foliage is attractive, and the branching habit is picturesque (*Hosely 1938*). And sassafras is a good choice for restoring depleted soils in old fields. It was superior to black locust or pines for this purpose in Indiana and Illinois (*Auten 1945*).

PROPAGATION

Planting stock is available commercially from several nurseries in east-central states, and seed is provided by at least one dealer in Pennsylvania (*Landscape Materials Information Serv. 1966, Mattoon 1959, Northeast Reg. Tech. Serv. Cent. 1971, U. S. Forest*

Service 1972).

Sassafras can be propagated from seeds or root cuttings collected locally.

Ripened fruit can be picked from the trees or shaken down onto drop cloths. Because birds often quickly consume the fruit (*For-dham 1967*), it should be collected as soon as ripe—when dark blue and soft. The pulp can be removed by rubbing the fruits over hardware cloth of a mesh fine enough to hold the seeds, and washing away the debris with water. The cleaned seed can be air-dried briefly but should not be allowed to dry out or heat before storage or sowing. Sassafras seed does not keep well (*Fisher et al 1935, Clark 1962*) and should be placed in sealed containers at 35 to 41°F if to be stored for more than a few days (*U. S. Forest Service 1948*). Seeds should not be frozen. Storage by stratification in sand or sand/peat at 35 to 41 F has also been suggested (*U. S. Forest Service 1948*). The number of cleaned seed per pound is about 4,000 (3,000 to 6,000). Samples of commercial seed have been about 85 percent sound.

Optimal treatments for seed propagation are unknown. Apparently seeds from the north are more difficult to germinate than those from the south (*U. S. Forest Service 1948*) and may require warm stratification or some equivalent followed by cold stratification (*Franz L. Pogge, personal communication*). The latter treatment only, at 41°F for 30 days, has been recommended for seeds from southern areas (*U. S. Forest Service 1948*). However, some lots of seed did not germinate in less than 80 days in the germinator, regardless of several storage conditions and pretreatments (*Earl W. Belcher, personal communication*). Since response may be slow at best, tetrazolium or other quick tests may be in order to determine viability of seeds in storage or stratification.

Sassafras has been field-grown successfully from direct fall seeding (*Hosely 1938*). Seed cleaning was considered unnecessary by Fisher et al (1935), but other investigators suggest that cleaned seed gives better results than whole fruits, and that sowing should be done late in the fall to prevent seeds from germinating too soon. This requires cold storage or cold stratification between seed collection and sowing dates (*U. S. Forest Service 1948*). How-

ever, some inconsistencies among these findings emphasize need for additional study of sassafras propagation from seed.

Seeds or whole fruits can be sown in drills 8 to 12 inches apart and covered with $\frac{1}{4}$ to $\frac{1}{2}$ inch of firmed soil. For fall seeding, a mulch of burlap, straw, or leaves, held in place by bird or shade screening, is desirable until after late frosts in the spring. Spring sowing of stratified seed can be done as early as soil conditions permit, and the beds should be kept moist until germination is complete. No shading is required. Later, the seedlings can be lined out in beds of moist, rich, loamy soil with leaf or litter mulch (*U. S. Forest Service 1948*).

Sassafras can be propagated fairly well from root cuttings, but not from stem cuttings (*Halls and Alcaniz 1965a, Pogge 1970*). Among six kinds of stem or root cuttings collected in Pennsylvania in the spring, best results were from large root sections, about 4 to 7 inches long, which already bore a live stem sprout. These cuttings were planted vertically in fine soil and the soil was kept moist. After 5 months, 80 percent of the cuttings had formed rootlets. The next best kind of cutting was a 4.5 to 6.5-inch section of a large root (0.4 to 1.0 inch diameter) planted horizontally (*Pogge 1970*).

Smaller root cuttings are used. Starting in December, usually, a section about $\frac{1}{2}$ inch long is placed horizontally in a small pot using a 2:1:1 mixture of peat, loam, and sand. The pot is filled to within 1 inch of its top, and the cutting is covered with $\frac{1}{2}$ inch of sand. Pots are then set in ashes or sand, watered well, and covered with paper. When well established, the plants are usually repotted and hardened off in cold frames (*Sheat 1963*). Alternatively, field-collected suckers can be lined out in rows and kept moist.

The best method of propagating sassafras in the field is by suckers. Suckers, often freely produced, can be dug and moved immediately; but it is better if they are cut around with a spade and allowed to remain in place for one season. This will stimulate sucker root growth. Most suckers are not well rooted and are rather difficult to transplant without careful

handling. Older plants are difficult to transplant because of their long taproots.

If direct-seeding in the field is tried, the best seedbed is a moist, rich, loamy soil partially protected by vegetative cover or litter. Cleaned seed or ripe fruit should be covered with $\frac{1}{2}$ inch of firmed soil. With favorable conditions, germination may occur in the same fall, but generally takes place in the following April and May. Young plants should be protected from browsing animals, but usually should not be shaded.

MANAGEMENT

In establishing new stands of sassafras, seedlings or plantings should be arranged so they will eventually form compact groups. Maintaining established stands is not difficult except where browsing removes more than one-fourth of the annual growth from young plants. Well-established stands in full sunlight are often dense enough to compete with other trees and shrubs, but other less desirable trees should not be allowed to overtop the sassafras.

Because natural reproduction from seed is usually sparse and erratic, regeneration from root suckers and stump sprouts is usually more reliable.

Fire may serve, accidentally or intentionally, in preparing sites for sassafras, but the species is highly susceptible to fire damage at all ages. Light fires kill seedling and sapling-size trees, and more intense fires injure large trees and provide entries for root and butt rots.

From New York to Florida the larvae of the wood-boring weevil *Apteromechus ferratus* can kill trees up to 10 inches dbh, and sassafras foliage is a favorite food of Japanese beetles (*Popillia japonica*). Serious damage by these insects should be controlled, but except for small local outbreaks, insect damage is relatively unimportant to sassafras (*U. S. Forest Service 1965*).

Sassafras can be rather easily killed or set back if such control is necessary. It is susceptible to burning and to many herbicides, including AMS, fenac, fenuron, fenuron TCA, monuron, 2,4-D, 2,4,5-T, and 2,3,6-TBA (*Dunham 1965, Gysel 1961, Nation and Lichy 1964*).

SERVICEBERRIES

Amelanchier Med.

Amelanchier arborea (Michx. f.) Fern.,

Amelanchier bartramiana (Tausch) M. J. Roem.,

Amelanchier X. grandiflora Rehd.,

Amelanchier laevis Wieg., and

Amelanchier sanguinea (Pursh.) DC.

Also called Juneberry, Serviceberry, Shadblow, and Shadbush.

By Joseph S. Larson

*University of Massachusetts
Amherst*

SPECIES

Botanists have not agreed on the classification of serviceberries, and land managers may not be able to distinguish among species. Accordingly, serviceberry is treated here as a group of similar species.

RANGE

Serviceberries grow throughout the Northeast.

Amelanchier arborea (formerly *canadensis*) ranges west to southern Ontario, northern Michigan, and eastern Minnesota, south to southeastern Nebraska, eastern Oklahoma, eastern Texas, Louisiana, and northern Florida.

Amelanchier bartramiana ranges north to Labrador and Newfoundland, and west to

northern Michigan and northeastern Minnesota. In the United States it is a several-stemmed shrub less than 10 feet high, but becomes a small tree in its northern range (Nova Scotia).

Amelanchier X. grandiflora is a large-flowered hybrid (*A. arborea* X *laevis*) ranging west to Missouri, south to Georgia and North Carolina, and is also found in cultivation.

Amelanchier laevis ranges west to Minnesota, eastern Kansas, Missouri, and Indiana, and south in the mountains to Georgia and Alabama.

Amelanchier sanguinea, which may reach proportions of a small tree 10 to 23 feet high, ranges west to northern Minnesota, northern Iowa, and southern Michigan, and is found in the mountains of western North Carolina (Little 1953).

Species in this genus grow in all of the 48

contiguous United States, Alaska, and the Canadian Provinces.

HABITAT

As a genus, serviceberry is acclimated to all the extremes found within the Region. Among the five species, *A. bartramiana* occurs at most northern latitudes and not south of northeastern Pennsylvania. *A. X. grandiflora* is found at latitudes from New Hampshire south. *A. sanguinea*, except for locations in mountainous North Carolina, remains north of New Jersey, and northern Ohio. *A. arborea* and *A. laevis* occur at all latitudes within the region, the latter preferring higher elevations at southern latitudes (Little 1953).

Serviceberry occurs most frequently in swampy to moist, slightly acid soils (pH 6.0 to 7.0) and along watercourses, although *A. laevis* and *A. arborea* will occupy dry upland sites. In Michigan *A. arborea* occupies sandy soils with pH as low as 4.0 (Hosley 1938). At the southern reaches of its range *A. bartramiana* occupies the higher altitudes (Pa.) as does *A. laevis* south of the Maryland-Pennsylvania region (Gleason and Cronquist 1963, Little 1953). Growth and fruit production are generally best in full sunlight, but the serviceberries tolerate shading.

The former oak-chestnut forest, now a grouping of red oak, chestnut oak, white oak, red maple and sourwood, with some Virginia and pitch pine included, supports serviceberry. In the northern coniferous forest, serviceberry is found with sheep-laurel, viburnums, clintonia, and Labrador tea. It is a forest-edge species associated with aspen, chokecherry, hazelnut, rose, and birch (Shelford 1963). Old fields, coastal pine barrens, limestone hills, and barrens are other communities supporting serviceberry (Gleason and Cronquist 1963). On sand-flats along the Hudson River it is an invader in the shade of cottonwoods (McVaugh 1957).

LIFE HISTORY

The time of flowering is late March to May. The white flowers in terminal clusters often appear before the leaves, being among the earliest woodland trees and shrubs to produce

showy flowers. The fruit ripens, depending on the species, from late June to August. In several species the fruit is sweet and juicy, while some are small and dry (U. S. Forest Service 1948).

Information about seed production is sparse except for results of a West Virginia study in which 20 serviceberries averaging 3.2 inches in stem diameter were observed during 4 years. The crop failed in one year. Average fruit yield per plants was 2.4 quarts, and the fruits persisted on the plants until August 1. More than 70 percent of the plants bore some fruit except in the crop-failure year (Park 1942).

Seed production per plant is otherwise unknown. The numbers of seed per pound vary from 50,000 to 113,000, with an average of about 83,000. Small abortive seeds are numerous and are not included in these figures (U. S. Forest Service 1948).

Seed dispersal, almost entirely by animals and birds, usually takes place about as soon as the fruit ripens (U. S. Forest Service 1948). Sowing may be done on open ground in the spring, summer, or fall (Kains and McQuesten 1951), or seeds may be stratified and sown in the spring or sown in the nursery and transplanted (U. S. Forest Service 1948).

Serviceberry reproduces from seeds, from cuttings taken in the fall or spring, or from suckers (U. S. Forest Service 1948).

USE BY WILDLIFE

Twigs and foliage may constitute $\frac{1}{2}$ to 2 percent of the diet of white-tailed deer; fruit and buds may comprise $\frac{1}{2}$ to 2 percent of a ruffed grouse's diet; and the fruit, bark, and twigs may be 2 to 5 percent of the diet of the eastern fox squirrel. Many song birds and small mammals eat the fruits; and turkey, beaver, skunk, red fox, moose, eastern flying squirrel, raccoon, black bear, cottontail rabbit, and eastern red squirrel are known to consume the fruit, bark, or twigs (Bump et al 1947, Hosley 1956, Martin et al 1951, Van Dersal 1938). In the bear oak forest type it receives moderate use by white-tailed deer (Bramble and Goddard 1943).

Chemical analysis of *A. canadensis* fruits (Wainio and Forbes 1941) and *A. laevis* twigs (Bump et al 1947) have been reported.

The spring flowers give serviceberry an aesthetic value equal to its wildlife food value.

PROPAGATION

Though seed and stock are available commercially, it is doubtful that the cost can be justified for wildlife purposes alone. Cuttings, taken from vigorous specimens in the spring or fall, or suckers may be a more practical source for small-scale wildlife plantings. Root cuttings and softwood cuttings 3 to 6 inches long root most readily, and use of bottom heat and root hormone treatment have been recommended (Harris 1961). Commercial seed is over 90 percent pure and soundness averages about 80 percent (U. S. Forest Service 1948).

Optimum seed-storage conditions are unknown, but dry storage in sealed containers at 41°F. has been successful. Seed dormancy can be overcome partly by low-temperature stratification and scarification. Immersion in concentrated sulfuric acid for 30 minutes, combined with stratification, may be helpful.

Seeds are usually either fall sown, or stratified and sown in the spring in mulched beds. Drills of 25 viable seeds per linear foot, covered with $\frac{1}{4}$ inch of nursery soil are recommended. Nursery germination is about 40 percent; beds should be half shaded for the first year, transplanted after 1 year and field planted 2 to 3 years later (U. S. Forest Service 1948).

Seeds after-ripen more quickly and germinate better after dry storage and stratification at 34 to 41°F. for 3 to 5 months. After-ripening does not occur at 50°F., and no seedlings result when sown in a 70°F. greenhouse without previous cold treatment. Fall planting in a cold frame gives good seedling production (Crocker and Barton 1931). One test yielded 10,000 usable plants per pound of seed (Van Dersal 1938).

Serviceberry seed can be sown on open ground, but no data are available on success or procedure (Kains and McQuesten 1951).

MANAGEMENT

On intensively managed areas and in locations where the public has ready access, it seems worthwhile to protect and encourage serviceberry for combined aesthetic (flower) and fruit-producing values. It is apparently very susceptible to 2,4-D (Blaisdell and Muegler 1956) and may suffer heavy mortality when this herbicide is applied in control operations.

MISCELLANY

The taxonomic confusion among current authorities, at least in terms of name changes, makes use of the literature rather difficult if one is interested in the plant at the species level. It seems best to use Little (1953) as the basic authority on species names and ranges, though Gleason and Cronquist (1963) are more recent and differ markedly with Little in several respects. Little relies on the one monograph I have found on the group (Jones 1946), while Gleason and Cronquist appear to continue older designations.

Whichever authority is chosen, there is still difficulty with non-taxonomic references because one cannot be sure which system the author has used or whether he was competent to identify some of the more difficult species.

Infusions and tinctures of the dry flowers of *Amelanchier* are reported to be both a hypotensive and cardiotonic drug and a source of vitamin B₁₂ (Pisarev and Beisekova 1965). *Amelanchier* is a host for the cedar apple fungus, which produces leaf and fruit spots on apples (Van Dersal 1938) and a host to *Tympanis amelanchieris*, a minor fungus pathogen (Groves 1952).

COMMON SPICEBUSH

Lindera benzoin (L.) Blume
Formerly *Benzoin aestivale* (L.) Nees,
or *B. benzoin* (L.) Coulter.

Also called Allspice Bush, Benjamin-Bush, Blume, Feverbush, Pepperbush, Spiceberry, Spicebush, and Wild Allspice.

By Gene W. Wood

Pennsylvania State University
University Park

RANGE

Common spicebush occurs throughout most of the East, ranging north to southern Ontario and southwestern Maine. Along the southern portions of the Northeastern and Great Lakes States, the typical form overlaps the range of a variety [*L. b. pubescens* (Palmer and Steyermark) Rehd.], which ranges southward to Florida and Texas (Fernald 1950, Gleason 1963b, Strausbaugh *et al* 1931).

HABITAT

Spicebush is found most often as a forest understory shrub in deciduous stands of advanced growth. It seldom forms dense communities, but may persist in forest openings (Van Dersal 1938). Its most common associate in the oak-hickory and mixed oak types is white oak. In coastal hardwood areas it may be found beneath swamp white oak. In the northern hardwood type, sugar maple, red maple, beech, sweet birch, and yellow birch most often form the overstories where this shrub grows. In western New York spicebush is commonly found in beech-American elm as-

sociations. In northern New Jersey, spicebush uniformly occurred in the most mesic (moist) sites, exemplified by ravines and north-facing slopes, and outranked all other shrubs and vines in this characteristic (Davidson and Buell 1967).

Typically, spicebush grows best on shaded, moist to well-drained sites in damp woods and along streams. The most favorable soils are fairly moist throughout the year, relatively fertile, high in organic matter, and moderately acidic (Van Dersal 1938). The optimum pH range is about 4.5 to 6.0 (Spurway 1941).

LIFE HISTORY

The yellow to greenish-yellow flowers appear as early as March or April in some parts of the range and always before leaf-bud break. The flowers occur in dense clusters at the nodes of the last year's shoots. A fleshy, scarlet drupe, approximately 0.4 inch long, is produced from each flower and ripens in September to October, or earlier in the south (Van Dersal 1938). One oval seed is contained in each fruit. The seed is light violet-brown with

flecks of darker brown (*U. S. Forest Service 1948*). Spicebush seed closely resembles that of sassafras (*Martin and Barkley 1961*). Three criteria that may separate the two are: sassafras is slightly shorter, the seed coat of sassafras is twice as thick, and sassafras is a solid dark brown while spicebush is mottled.

Seed production with respect to age is not well documented. Spicebush fruited for the first time at 3 years of age, among wildlings under little or no shade, in Connecticut (*Spinner and Ostrom 1945*). The shrub is not a heavy seed producer at any age, but older individuals seem to be better producers than young ones, and those exposed to full sunlight or light shade commonly produce better than those under dense cover. One hundred pounds of fresh fruit yields 15 to 25 pounds of cleaned seed. The number of cleaned seed per pound is 4,500 to 4,600 (*U. S. Forest Service 1948*).

Spicebush reproduces from seed, sprouts, and suckers; the latter two are the most common under natural conditions. Reproduction from seed will most likely occur where the overstory is removed sufficiently to warm up the damp soil that the plant requires. Increases in sprouting and suckering also occur under these conditions, often resulting in dense clusters of stems.

Growth will usually be best under light shade and on warm but very moist sites. Height growth rates under optimum conditions are not documented, but probably are about 12 to 24 inches per year in the early years. Spicebush may attain a height of 15 to 16 feet, but this is unusual in northern areas where mature plants generally range from 4 to 8 feet tall.

Spicebush is highly shade-tolerant, almost always being found under a canopy of some type. It is not an invader of openings such as old fields, and is a poor competitor for the better sites.

USES

The leaves and shoots are sometimes browsed by deer, usually as a pastime food. They are not preferred or staple deer foods in central Pennsylvania or western New York. The fruits are eaten by many birds, including

ruffed grouse, wild turkey, ring-necked pheasant, bobwhite quail, catbird, crested flycatcher, eastern kingbird, robin, graycheeked thrush, hermit thrush, and red-eyed vireo. The veery and wood thrush are particularly fond of spicebush fruits (*Martin et al 1951*). Because of its usual sparse growth habit, spicebush provides little in the way of cover for wildlife.

The aromatic bark of spicebush is said to have medicinal value for treatment of dysentery, coughs and colds, and as a vermifuge (*Krochmal et al 1969*).

PROPAGATION

Seeds are available at few supply houses, but may be available from Forestry Associates, Box 1069, Allentown, Pennsylvania. Seeds ordinarily lose viability quickly. Storage life may be lengthened by omitting the customary drying (*Swingle 1939*) and keeping seeds in sealed containers in a refrigerator or cold room (*U. S. Forest Service 1948*).

Spicebush seeds can be stratified to activate the dormant embryo. Stratification at 77°F for 15 to 30 days followed by 34 to 41°F for 90 to 120 days has been recommended (*U. S. Forest Service 1948*). Nearly as good germination resulted from stratification at 41°F for 120 days (*Barton 1939*).

The seed may be sown in the fall or spring. When fall sowing is done, the seed should be mulched over winter and the mulch removed in the spring. In areas of severe winter temperatures, the seed should be stratified below the frost line in the fall, and removed and sown in the spring. All planting should be done on moist soils of high organic matter content.

Cuttings ordinarily do not root easily (*Hottes 1931*), but spicebush is sometimes propagated from cuttings of half-ripe shoots taken in September (*Doran 1957, Osborn 1933*).

Field planting of spicebush is not reported in the literature. Presumably, plants can be propagated in the field directly from seed as well as from nursery stock. Field planting of seedlings will probably meet with greatest success on moist partially shaded sites.

MANAGEMENT

The main management objectives for this shrub would be as a food source for song birds and for landscaping. Management for browsing species of animals would probably not be worthwhile. For decorative purposes, the yellow flowers are attractive in early spring before the leaves open, and the red fruit and clear yellow foliage are showy in early fall (Kammerer 1934).

The species will be most responsive to a thin overstory canopy that results in diffuse

light conditions and maintenance of high soil moisture. Spicebush can be produced in full sunlight, as on clearcut areas, so long as the moisture is adequate. Attempts at production on droughty unprotected sites will most likely fail.

Foliar as well as stump applications of ammonium sulfamate, 2,4-D, or 2,4,5-T will control this shrub, but it is resistant to amitrole (*Dunham 1965*). Several of the pelleted herbicides—fenuron, picloram, and dicamba—may also be used effectively.

SPIREAS

Also called Meadowsweet and Pipestem.

BROADLEAF MEADOWSWEET, *Spiraea latifolia* (Ait.)
Borkh.

DWARF or CORYMBED SPIREA, *Spiraea corymbosa* Raf.

HARDHACK SPIREA or STEEPLEBUSH, *Spiraea tomentosa*
L.

NARROWLEAF MEADOWSWEET or PIPESTEM, *Spiraea alba* Du Roi

VIRGINIA SPIREA, *Spiraea virginiana* Britt.

By Earl L. Core

West Virginia University
Morgantown

RANGE

About half a dozen kinds of native spirea occur in the Northeast. Of these narrowleaf meadowsweet or pipestem is by far the most common and has the widest range, extending from southwestern Quebec to North Carolina and westward as far as northern Missouri to Saskatchewan. Virginia spirea is the rarest, occurring in sporadic colonies from West Virginia south to Georgia (Clarkson 1959, Gleason 1963b, Strausbaugh and Core 1953). Introduced species may escape from cultivation.

HABITAT

Virtually all climatic zones represented in the Northeast include one or more of the spireas. Spireas grow well on a variety of soils. Narrowleaf meadowsweet occurs in wet meadows and swamps, often forming extensive

thickets in glady regions in the mountains. Hardhack or steeplebush is also found in mountain swamps, usually at somewhat higher elevations. Dwarf and broadleaf spirea, on the other hand, are more likely to be found on dry, rocky soil in mountain woods or old fields. Most species occur in neutral soil, but hardhack appears to prefer acid soils (Laurie and Chadwick 1931:79, Wherry 1957).

Narrowleaf meadowsweet forms part of a shrub community including alders, willows, and silky dogwood. Southward this community may be succeeded by elms, maples, white ash, and black cherry; northward by larch, birches, aspens, black ash, and conifers.

LIFE HISTORY

The white or pink flowers are usually numerous. Flowering occurs mostly in June and July, but may extend as late as September.

Pollen is carried by insects, chiefly bees. The fruit is a dry capsule, with two or several seeds, ripening in late summer. It is not known at what age seed-bearing begins, but it is quite likely at less than 10 years.

Published information about growth rates or natural methods of regeneration could not be found. Growth of narrowleaf and broadleaf meadowsweet is more vigorous in full sunlight than in shade. The other species appear to do better in some shade. Meadowsweet (*S. alba*) is slowly replaced by taller plants, except on the wettest sites.

USES

Deer browse meadowsweet and perhaps other species, but the plants are low in preference. Hardhack is apparently ignored by white-tail deer in Massachusetts (Van Dersal 1938). Other observed feeders are ruffed grouse and cottontail rabbits. Westward, in the Great Lakes region, prairie chickens eat the seeds and browse on buds and leaves (Martin et al 1951). Spireas are locally important as cover for cottontails, and, along with alders and willows, they are a common part of woodcock habitat.

Indians and early settlers used the stems of meadowsweet for pipe stems, whence the name pipestem, widely used in southern West Virginia (e.g. Pipestem State Park, in Summers County).

PROPAGATION

Many kinds of spireas are available for planting, but culture methods are more or less similar. All are easy to move and to grow. They need no special types of soil, although some do best in swamps while others prefer

drier soil. They thrive in sun and some will grow well in light shade (Zucker 1966). There are no particular insect or fungus pests.

Propagation is usually by cuttings, both softwood and hardwood. Leafy softwood cuttings made in summer and rooted under high humidity usually succeed; treatment with one of the root-promoting substances is beneficial. These root hormones increase the percentage of cuttings that form roots, as well as the number and quality of roots, thus ensuring uniformity of rooting. The presence of leaves on softwood cuttings greatly aids in root development. Some species of spirea can be started readily by hardwood cuttings planted in early spring (Doran 1957, Hartmann and Kester 1968).

Spireas may also be propagated by seeds planted in nursery beds in spring.

Meadowsweet and hardhack are recommended as excellent and good respectively, for planting for roadside and wildlife use in Wisconsin (Natural Resources Committee 1967).

MANAGEMENT

There is a lack of information about the ecology and management of this genus. When the editors polled biologists to determine what plants should be included in this publication, the spireas were ranked as moderately important for cover throughout northeastern North America. Only in Maine, Rhode Island, and Delaware were spireas considered of no importance. Despite this, there apparently has been no direct management for the spireas. Spireas can be controlled with the herbicides diuron, simazine, and 2,4,5-T applied according to the manufacturer's recommendations (Dunham 1965).

SUMACS

SMOOTH SUMAC, *Rhus glabra* L. Also called Common Sumac, Pennsylvania Sumach, Scarlet Sumac, Shernoke, Upland Sumach, and Vinegar Tree.

STAGHORN SUMAC, *Rhus typhina* L. Also called Hairy Sumac, Velvet Sumac, and Vinaigrier.

By Hanley K. Smith

*Michigan State University
East Lansing*

SPECIES

The species are staghorn sumac, *Rhus typhina*, and smooth sumac, *Rhus glabra*. An early technical name for staghorn, *R. hirta* (L.) Sudw., is common in older literature but is no longer valid. Smooth and staghorn sumac may hybridize, but this has not been demonstrated conclusively. Apparent intergrades are often recognized by the following names: *R. pulvinata*, *R. glabra* x *typhina*, *R. borealis* and *R. glabra* var. *borealis* (Little 1945).

RANGE

Smooth sumac is native throughout most of southern Canada, from southwestern Quebec to southern British Columbia, and all of the 48 contiguous United States. Staghorn sumac occurs naturally from Nova Scotia and the Gaspé Peninsula of Quebec south to North Carolina and west to southern Ontario, Minnesota, and Iowa (Barkley 1937, Little 1953). Both species have been planted widely for erosion control and as ornamentals.

HABITAT

The climate of the northeastern United States is not thought to be limiting to either species, but neither one extends far northward into Canada. Smooth sumac is the more widespread of the two species, probably because of its greater resistance to droughty conditions.

Both species are open-growing pioneer shrubs or small trees, and are usually found on well-drained soils. Typical growing sites include abandoned fields, roadsides, railroad right-of-ways, fence rows, burned or denuded areas, and young forest plantations (Boyd 1943, Clements 1920, Verte 1957). Smooth sumac is characteristic of the forest-prairie ecotone of the midwestern United States (Bray 1960), and both species are common on the abandoned farmlands of the northeastern United States and southeastern Canada (Hirth 1959). And optimum pH range of 5.0 to 6.0 has been reported for both species (Spurway 1941).

Associated species usually include the various old-field pioneer herbs, shrubs, and trees.

In Michigan these species include strawberry, blackberry, red oak, downy serviceberry, quaking aspen, and black cherry (*Smith 1970*). In Connecticut, blackberry, common juniper, eastern redcedar, northern bayberry, and red maple are common associates of smooth sumac (*Hirth 1959*). Sumacs are occasionally found growing under a recently closed forest canopy. This situation is usually temporary, as the vigor and reproductive capabilities of sumacs are hindered under shade conditions (*Smith 1970*).

LIFE HISTORY

In both species, plants usually bear either male or female flowers, not both sexes; but clones with both sexes on the same plant are found occasionally. Flowering occurs in June to July. The fruit matures in August to September (*Gilbert 1959*), and fruits commonly persist on undisturbed plants until the following summer. Both species are insect-pollinated.

The fruiting head is a compact cluster of red hairy drupes, each drupe about $\frac{1}{4}$ inch in diameter and containing one seed. Seed production is usually heavy, and each fruiting head may contain 100 to 700 seeds (*Lovell 1964*). The number and size of fruiting heads on a plant is variable, depending on age and vigor of the plant. A single acre of mature sumac may produce more than 3,500 fruiting heads (*Smith 1970*). The minimum fruiting age is usually 3 to 4 years (*Smith 1970, Spinner and Ostrom 1945*). The maximum fruiting age is unknown, but probably seldom exceeds 35 years on undisturbed sites. Among vigorous plants, fruit production is consistent and crop failure seldom occurs.

Sumac seeds are oval, smooth, 2 to 3 mm long, have an extremely hard seed coat, and exhibit mechanical dormancy (*Heit 1967b*). Enhanced germination of sumac seeds has been shown after their passage through the digestive systems of jackrabbits (*Brown 1947*), a ring-necked pheasant (*Swank 1944*), and quail (*Krefting and Roe 1949*); and it is assumed that seeds are disseminated in the droppings of various wildlife species.

Though invasion of new areas is by seeding, established sumac reproduces primarily from root sprouts. Typically, both smooth and staghorn sumac grow in a circular clone, the older stems in the center and the younger stems radiating outward. The lateral root system, from which the new stems arise, is elaborate, and has been reported to spread outward at a rate of about 3 feet per year. The clone begins to lose vigor at about 15 years, death of the aerial portions proceeding outward from the older center stems (*Gilbert 1966*).

Smooth sumac may reach a height of more than 12 feet, but is commonly less than 6 feet tall. Staghorn sumac is generally taller, with mature clones usually exceeding 6 feet in height. Plants in excess of 30 feet have been recorded, but these are considered uncommon (*Smith 1970*).

Sumac is characteristic of highly disturbed or denuded areas. Competition from other plants in these areas is negligible because unfavorable environmental conditions eliminate many competitors. In normal old-field succession, sumac fails to compete successfully with invading tree species and is seldom found growing under a closed forest canopy. The plants may also be adversely affected by a lack of available water, resulting from intense root competition or low rainfall (*Weaver 1919*).

Sumac is of limited economic importance and, consequently, reports of its diseases are rather uncommon in the literature. Several sumac species are known to be infected by fungi of the genera *Pileolaria*, *Fusarium*, *Cryptodinporthe*, *Physalospora*, *Verticillium*, and *Sphaerotheca* (*Pirone et al 1960*). A fungus of the genus *Pythium* commonly infected seedlings raised in the laboratory (*Lovell 1964*). In Michigan, the mite *Eriophyes rhois* and the moth *Holcocera chalcofrontella* have been observed to cause extensive damage to the foliage and fruit, respectively, of both smooth and staghorn sumac (*Smith 1970*).

USES

Ring-necked pheasants, bobwhite quail, wild turkey, and about 30 species of song birds include sumac fruit in their diets (*Martin et al 1951*). Sumac fruits are eaten by

many upland game birds, but are known to be important only in the winter diets of the ruffed grouse (*Bump et al* 1947) and the sharp-tailed grouse (*Ammann* 1957). The hard seeds of sumac sometimes function as grit for ruffed grouse (*Edminster* 1947). Fox squirrels (*Packard* 1956) and cottontail rabbits (*Hickie* 1940) include sumac bark in their diets during winter.

The fruit and stems of sumac are important winter foods for white-tailed deer throughout the eastern United States (*Banasiak* 1961, *Hosley and Ziebarth* 1935). In northern Michigan, sumac fruit and stems are heavily browsed by deer from October to March, the most intense browsing occurring in December and January (*Smith* 1970). When a fruit is browsed, the entire inflorescence is eaten. Browsing of stems, by contrast, usually consists of eating the outer 2 to 3 inches of the twig. Vigorous stands of sumac may produce in excess of 120 pounds (oven-dry weight) of fruit and stem browse per acre (*Smith* 1970).

The proximate analyses of the stems and fruit of smooth and staghorn sumac collected in Michigan indicate little difference in nutritional composition between species. Sumac was low in crude protein, high in ether extract, and similar in gross energy as compared to three other common deer browse species: northern white-cedar, jack pine, and bigtooth aspen (*Ullrey et al* 1964; *Ullrey et al* 1967). The following analyses are expressed on a fresh-weight basis (*Smith* 1970):

Item	Smooth sumac		Staghorn	
	Stem	Fruit	Stem	Fruit
Percentage composition:				
Dry matter	59.29	94.06	56.85	94.06
Cell-wall constituents:	25.22	53.59	22.98	49.77
Cellulose	12.57	21.68	11.80	18.88
Hemicellulose	5.24	14.05	4.60	15.23
Lignin	7.41	17.86	6.58	15.66
Cellular contents:	34.07	40.49	33.87	44.69
Soluble carbohydrates	21.01	18.10	20.61	22.83
Crude protein	3.45	5.24	3.85	5.01
Ether extract	6.54	13.80	6.22	13.89
Ash	3.08	3.35	3.10	2.96
Gross energy (kcal/g)	2.83	4.71	2.72	5.00

Sumacs offer very little winter cover for wildlife. Because they are often the largest and most common woody plants in old fields or forest openings, they provide spring and summer wildlife cover. However, they are not

important cover species and should not be established for that purpose.

Since both species have attractive fall foliage and persistent fruits, they are recommended as ornamental shrubs, particularly for dry, open sites where there is room for the plants to spread (*Holweg* 1964, *Zucker* 1966). Smooth sumac may be slightly better than staghorn for stabilizing dry sandy banks, screening, or roadside uses (*Wisconsin Conservation Department* 1967, *Zucker* 1966).

Sumac is also a source of tannic acid, although commercial production for this purpose is limited to Asia and Europe. Preparations of the fruits are used in folk medicines. Common uses include astringents, antidiuretics, and tonics (*Krochmal et al* 1969).

PROPAGATION

Seeds of both species are commercially available from a few suppliers. However, large quantities of seeds can be harvested readily from wild stock from September to December, as each fruiting head may produce more than 500 viable seeds.

Yields of cleaned seed per 100 pounds of fruit have been reported to be as low as 14 pounds (*Smith* 1970) and as high as 50 pounds (*U. S. Forest Service* 1948). The average number of cleaned seed per pound of smooth sumac has been reported to be as high as 69,000 (*Krefting and Roe* 1949) and as low as 46,000 (*Smith* 1970). The number of seeds per pound of staghorn sumac has been reported as 53,000 (*Krefting and Roe* 1949) and 60,000 (*Smith* 1970).

Seeds harvested in the field are encased in a dry, leathery pericarp. To extract large numbers of seeds, the fruits should be dried for 3 days at 110°F, placed in a cloth bag (½ pound of fruit in a 10 x 16-inch bag), and vigorously pounded against a hard surface for about 2 minutes. Motorized grain-threshing equipment does not work as well. The contents of the bag should then be placed in a tray of water and stirred. The viable seeds will sink to the bottom of the tray, while the defective seeds and debris will float. The water should then be poured off and the seeds retrieved, air-dried, and stored in sealed glass bottles. Over 90 percent of the seeds cleaned

in this manner germinated after proper scarification (*Smith 1970*). The seeds do not require special storage procedures and may be kept in sealed containers for a few years without loss of viability, but should be held at low temperatures if they are to be stored for many years (*Heit 1967b, Heit 1967e*).

Neither species of sumac shows internal seed dormancy, but both are extremely hard-seeded, and acid scarification is required to prepare them for germination (*Heit 1967b*). Optimum scarification time varies with the seed lots, but good results are usually obtained by placing the seeds in concentrated sulfuric acid for 1 to 4 hours (*Smith 1970*). Then, after washing and drying, no further pretreatment is necessary. It has been reported that up to 93 percent of properly treated sumac seeds will germinate within 10 days of planting (*Smith 1970*).

Sumac seed can be sown either in the fall or spring. Scarified seeds should be planted about $\frac{1}{4}$ to $\frac{1}{2}$ inch deep in moist sand or sandy loam. Very poor germination rates have been observed for seeds planted deeper than 1 inch (*Smith 1970*).

For the nursery, a seeding rate of 1 pound of seed per 100 square feet and a plant density of 10 per square foot have been recommended (*Edminster 1947*). Entire plants up to 1 year old may be transplanted with a high degree of success, if the soil surrounding the roots is kept intact (*Smith 1970*). Older plants may be transplanted with reasonable success, although more extensive root systems complicate the procedure. A recommended size for outplanting is 6 inches tall x $\frac{1}{8}$ inch caliper (*Edminster 1947*).

Field plantings may be established directly from seed. Scarified seeds covered with 1 inch of soil or less have the best chance of survival. Best results should be obtained by raking or disk ing an area broadcast at a rate of ten scarified seeds per square foot. But transplanting young plants from the nursery is a successful method of establishment, and is highly recom-

mended when the necessary manpower is available (*Smith 1970*).

Both species can be propagated from root cuttings taken in December. Staghorn sumac has been grown in England from late-summer stem cuttings (*Doran 1957*).

The bare, open, sandy soils on which sumacs may thrive often prove very droughty, and therefore may be lethal to young plants. For this reason, supplementary watering of newly established areas may be necessary during extended dry periods (*Smith 1970*).

MANAGEMENT

Staghorn and smooth sumac seem ideally fitted for establishment in abandoned fields, along roadsides, and on clearcut areas. They offer a valuable wildlife food, erosion control, and may be used to improve the appearance of recently disturbed or otherwise unsightly areas. Sumacs may be especially desirable in recently planted or newly cut conifer plantations and along forest roads.

A third, and perhaps the simplest method of propagation, involves rejuvenation through disturbance of established stands. Sumac often responds to disturbances such as plowing, fire, and cutting by sending up many young shoots from its root system. There are two situations when this response is especially useful. First, where the crown has grown beyond the reach of potential browsers. Cutting the tall stems will often promote root sprouting and thus restore available browse. Second, when a clone has begun to lose vigor and die. In this case, mowing or plowing may rejuvenate the clone, allowing it several more years of productivity. However, the magnitude of this response is proportional to the vigor of the clone (*Smith 1970*).

Sumac is difficult to destroy mechanically because of its prolific response to disturbance. However, the plants can be controlled by foliage sprays or other applications of various herbicides, notably D-T; 2,4,5,-T; AMS; furon; and 2,3,6-TBA (*Arend and Roe 1961, Dunham 1965, Egler 1949*).

SWEETFERN

Comptonia peregrina (L.) Coult.

By Sanford D. Schemnitz

*University of Maine
Orono*

RANGE

Sweetfern occurs throughout the Northeast, southward to northern Georgia and Tennessee, and westward to Manitoba, Minnesota, and parts of Indiana and Illinois.

HABITAT

The species tolerates a variety of conditions throughout the region. It is common on upland slopes where trees are sparse or absent (*Martin et al 1951*) and along roadsides and under powerlines. In Maine, sweetfern is often a major component of blueberry barrens and old fields. In Pennsylvania, sweetfern frequently invades burned-over areas and abandoned fields (*Grimm 1951*).

Optimum growing conditions for sweetfern have not been described, but good growth of the plant is often found on dry, well-drained, sterile, sandy soils. Sweetfern has root nodules, comparable to those on legumes and alders, which tend to enrich soil by fixing atmospheric nitrogen (*Ziegler and Huser 1963*).

LIFE HISTORY

The individual plant produces either flowers of only one sex or of both sexes. However each flower is unisexual, and the flowers appear in catkins clustered at the ends of the branches.

The male catkins are rather long and cylindrical; the female catkins are short and rounded. In winter the male catkins are prominent and erect.

The seeds are nutlets that mature in August and become available in September and October. They are contained in bur-like heads about $\frac{1}{2}$ inch in diameter. About 4 seeds or nutlets are found in each bur-like fruit. Each seed is about $\frac{1}{4}$ inch long, olive brown, and shiny. One hundred pounds of fresh burs will produce about 4 to 12 pounds of cleaned seed of about 4 percent soundness. Cleaned seed varied from 31,200 to 54,800 per pound. Germination rates were low (*U. S. Forest Service 1948*) in one test, but the reason was not investigated.

Mature plants are usually less than 3 feet tall but I found no information about growth rates. Much of the reproduction is via sucker growth from long underground stems. There is much variation in leaf form, with occasional compound leaves (*Berry 1906*). Sweetfern is intolerant of shading and usually grows best in full sunlight.

USE BY WILDLIFE

Sweetfern has long been considered valuable to wildlife for cover and browse (*McAtee*

1936). It was listed along with species commonly browsed by Maine deer in winter (*Banasiak* 1961). At Acadia National Park, Maine, 14 percent of the available twigs of sweetfern

had been browsed during the fall and winter by deer on 114 of 120 total plots.

The chemical composition of sweetfern, reported by three authors, is high in protein.

Authority	State	Date	Percent crude protein	Crude fiber	Fat	Percent N. free extract
Davenport (unpublished)	Michigan	3/8/37	13.3	22.1	5.6	55.7
Baird (1966)	Maine	8/10/65	9.7	14.6	6.5	67.0
Roop (1968)	Maine	Winter/66	10.8	—	—	—

Sweetfern buds, catkins and foliage are a very minor food of ruffed grouse throughout the region (*Edminster* 1947; *Martin et al* 1951). In extensive studies in New York in 1931-41, sweetfern was found as a trace in 0.002 percent of 1,632 grouse crops (*Bump et al* 1947).

PROPAGATION

I found no specific information.

MANAGEMENT

I found little information. Sweetfern thrived after 2,4-D and 2,4,5-T broadcast spraying of utility lines in Pennsylvania and New Hampshire (*Bramble* 1968, *Hodgdon* 1958). In contrast, good control was reported from eastern Maine where 2,4-D (2 pounds of ester per 100 gallons) was applied on blueberry fields (*Trevett* 1960). Ammonium sulfamate (3/4 pound per gallon) also controlled sweetfern among blueberries (*Smith et al* 1947).

Sweetfern sprouting vigor was increased by burning New Hampshire blueberry fields at 3-year intervals (*Smith et al* 1947).

MISCELLANY

Sweetfern is the alternate host of sweetfern blister rust (*Cronartium comptoniae*) a fungus that ranges from Nova Scotia south to North Carolina on hard pines. Jack pines are often attacked by the rust, trees less than 3 inches being girdled. The rust has been found in ponderosa pine plantations in Connecticut (*Boyce* 1938). Sweetfern is also the alternate host of the Saratoga spittle bug (*Aphrophora saratogensis*), which attacks pines in the East (*Boyce* 1938).

The leaves have been used as an ingredient in diet drinks and as a remedy for dysentery (*Billington* 1949). Sweetfern is also considered to be valuable for ornamental purposes (*U. S. Forest Service* 1948).

VIBURNUMS

MAPLELEAF VIBURNUM, *Viburnum acerifolium* L.

HOBBLEBUSH VIBURNUM, *Viburnum alnifolium* of authors,
not Marsh.

WITHEROD VIBURNUM, *Viburnum cassinoides* L.

NANNYBERRY VIBURNUM, *Viburnum lentago* L.

CRANBERRYBUSH VIBURNUM, *Viburnum opulus* L.

BLACKHAW VIBURNUM, *Viburnum prunifolium* L.

ARROWWOOD VIBURNUM, *Viburnum recognitum* Fern.

By James A. Rollins

*Nasson College
Springvale, Maine*

SPECIES AND RANGES

Viburnums are difficult to classify, and botanists have disagreed on some names. I have used the names given in the 8th edition of Gray's Manual (*Fernald 1950*), except that American and European cranberrybush are combined as one species (*McAtee 1956*) and simply called cranberrybush viburnum. Nomenclature used in much of the older literature may be confusing, particularly in regard to the forms whose names have included the word arrowwood. Table 1 shows some of the alternative common and technical names given in the literature, and the ranges of the seven species.

HABITAT

The viburnums included here are well adapted to the humid climate of northeastern North America (*Thornthwaite 1931*). Most species occupy nearly the entire climatic range of the Northeast except that cranberrybush and nannyberry grow mostly at higher elevations southward, and blackhaw is more typically a southern species. Arrowwood overlaps the range of southern arrowwood (*V. dentatum* L.) southward from Massachusetts Pennsylvania (table 1).

Blackhaw, mapleleaf, and witherod viburnums are often found on dry sites such as south-facing slopes (*Cantlon 1953*), ridge tops

Table I.—Viburnum names, ranges, and growth habits

Preferred names and synonyms		Common names	Scientific names	Occurrence	Growth habit
MAPLELEAF V.:	<i>V. acerifolium</i> L.			Quebec to Minnesota, south to Georgia and Tennessee; Dry or rocky woods.	Erect shrub, sometimes thicker-forming, to 6 feet.
HOBBLEBUSH V.:	moosewood, dockmackie, maple leaf arrowwood, possum-haw.	<i>V. alnifolium</i> of authors, not Marsh.; <i>V. grandifolium</i> Ait.; <i>V. lantanaoides</i> Michx.		Prince Edward Isle to Ontario and Michigan; south to Tennessee, Georgia, and North Carolina; woods and cool ravines; moist, well-drained soils. Tolerates low pH.	Erect or sometimes trailing shrubs to 10 feet, rarely to 15 feet.
WITHEROD V.:	wild-raisin, alisier.	<i>V. cassinoides</i> L.		Newfoundland to Manitoba, south to Tennessee, Georgia and North Carolina; thickets, clearings, swamps, borders of woods; moist or dry soils.	Erect, sometimes treelike shrub to 10 feet, rarely to 13 feet.
NANNYBERRY V.:	blackhaw, sheepberry, sweet viburnum, wild-raisin, alisier.	<i>V. lentago</i> L.		Manitoba to western Quebec, south to New England, New Jersey, Pennsylvania, Georgia; Ohio, Indiana, Illinois, northeast Missouri, South Dakota, Colorado, Wyoming. Borders of woods, streambanks. Tolerates low pH.	Erect, treelike shrub with slender branches, to 33 feet.
CRANBERRYBUSH V.:	Gelder rose, highbush cranberry, pimbinga, pin-cushion tree, quatre-saisons de bois.	<i>V. opulus</i> L.; <i>V. americanum</i> of authors, not Mill.; <i>V. o. americanum</i> Ait.; <i>V. trilobum</i> Marsh.		Europe, north Africa, northern Asia, British Columbia to Newfoundland, south to Nova Scotia, New England, Pennsylvania, northern Ohio, northern Indiana, northern Illinois, northeast Iowa, South Dakota, Wyoming, Washington. Cool woods, thickets, shores, rocky slopes. Moist, well-drained soils.	Erect shrub, to 13 feet.
BLACKHAW V.:	stagbush, sweethaw.	<i>V. prunijolium</i> L., <i>V. bushii</i> Ashe, <i>V. p. globosum</i> Nash		Texas, northern Florida, north to Connecticut, New York, Ohio, Michigan, Illinois, Iowa, Kansas. Thickets, borders of woods, streambanks, shores; moist or dry soils.	Erect shrub with rigid spreading branches, to 16 feet.
ARROWWOOD V.:	smooth arrowwood.	<i>V. recognitum</i> Fern. <i>V. dentatum</i> Fern. (ed. 7), not L.		New Brunswick to southern Ontario, south to southern New England, Long Island, South Carolina, northern Ohio, Michigan. Damp thickets.	Erect bushy shrub, to 10 feet.

(McIntosh 1959), or dry sandy loams in upland situations (Shreve et al 1910). However, they are not restricted to dry soils. In Pennsylvania, mapleleaf viburnum grew on such contrasting sites as strip-mine spoil banks (Bramble and Ashley 1955) and the moist rich loam of a north-facing slope (Harshberger 1919). Witherod was reported growing along swamps and bogs in Maine (Davis 1966, Hill 1923) and Kentucky (Braun 1950) as well as on the moist soils of spruce flats and slopes in Maine (Oosting and Reed 1944).

Arrowwood, cranberrybush, hobblebush, and nannyberry are usually found on wet or moist but well-drained soils. Soil composition does not have much influence on the occurrence of these species, and soil pH is usually not critical. Hobblebush and nannyberry are perhaps the species most tolerant of low pH.

Viburnums are characteristic of the shrub layer in the hemlock - white pine - northern hardwood forest (Hough 1936, Lutz 1930, Nichols 1935, Niering 1953), the spruce-fir forest (Davis 1966, McIntosh and Hurley 1964, Oosting and Reed 1944), and the mesophytic deciduous forest (Braun 1950). They also occur as forest-edge, hedgerow, roadside, stream bank, and bog-edge plants. By providing food and cover in these situations they are most valuable for wildlife. Once established, they are able to maintain their position during successional changes in the forest because of their high degree of shade-tolerance. They were present under the dense cover of the early virgin forests (Lutz 1930), although overbrowsing can permanently remove them from such stands (Gould 1966).

LIFE HISTORY

Viburnums in the Northeast generally flower in May and June (table 2). Blackhaw flowers slightly earlier, in April to June, and witherod a bit later, into July (Bailey 1935).

The small, white flowers are arranged in flat, rounded, or pyramidal clusters (cymes). The marginal flowers of the cyme are sterile in cranberrybush and hobblebush, and in some cultivated varieties of cranberrybush all of the flowers are sterile. The flowers of all species are attractive and make the plants desirable as ornamentals. Cranberrybush and hobblebush blossoms are the most showy.

The fruit is a fleshy drupe containing a thin flattened stone. Fruit size varies among species from $\frac{1}{4}$ to $\frac{3}{4}$ inch (table 2). Ripened fruits are dark blue or black in all species except the red-fruited cranberrybush. Ripening occurs most typically in late summer and early fall, but there is considerable variability among species and locations. The dates shown in table 2 are representative, but flowering and fruit ripening may occur a month or so earlier or later in some areas or years.

With the exception of hobblebush, I found no data about the yield of fruit or seed on a per-plant or area basis. For hobblebush, each fruiting stem yielded about 17 fruits, but the variation in yield from stem to stem was high (Gould 1966). However, since hobblebush normally occurs as a shrub layer under shade conditions that do not favor flower and fruit production, the yield of hobblebush fruit on a per-acre basis is low. Furthermore, in openings where flowering is enhanced, late spring frosts tend to kill the flowers and further reduce the

Table 2.—Viburnum flowering and fruiting characteristics

Species	Flowering	Fruit ripening	Seed dispersal	Color and size of ripe fruit
Mapleleaf	May-June	July-Oct	Fall	Purplish black, $\frac{3}{8}$ inch diameter
Hobblebush	May-June	Aug-Sept	Fall	Purple to black ¹ , $\frac{5}{16}$ inch long
Witherod	May-July	Sept-Oct	Fall	Blue to black, $\frac{1}{4}$ inch long
Nannyberry	May-June	Aug-Oct	Fall to spring	Blue-black, $\frac{1}{2}$ to $\frac{3}{4}$ inch long
Cranberrybush	May-June	Aug-Oct	Fall to spring	Orange to scarlet, $\frac{3}{8}$ to $\frac{1}{2}$ inch long
Blackhaw	Apr-June	Sept-Oct	Fall to spring	Blue-black, $\frac{5}{16}$ to $\frac{1}{2}$ inch long
Arrowwood	May-June	Aug-Sept	Fall-winter	Blue-black, $\frac{1}{4}$ inch long

¹Fruits are mature enough for germination when bright scarlet (Gould 1966).

Table 3.—Viburnum fruit and seed yields

Species	Number of dried fruits per pound	Pounds per 100 pounds of fruits	Cleaned seed			
			Thousands of seeds per pound	Low	Average	High
Mapleleaf	4,800	30	10.9	13.1	16.6	
Hobblebush	7,580	43 ¹		11.5		
Witherod	3,000	—	75.0	27.6	29.0	
Nannyberry	2,200	9.50	2.2	5.9	12.4	
Cranberrybush	5,500	6.33	9.4	13.6	17.8	
Blackhaw	—	20.50	4.0	4.8	6.0	
Arrowwood ²	—	25.30	14.6	20.4	32.6	

¹Weight per 100 pounds of dried fruit.²Species uncertain due to changes in names.

yield of fruit. An additional factor that may reduce the yield of fruit is the tendency for the flowers, immature fruit, and even the entire inflorescence to drop off if hit, brushed against, or otherwise disturbed.

The number of seeds per pound, the number of dried fruits per pound, and the yield in cleaned seed per 100 pounds of fresh fruit are given in table 3.

Seed dispersal in the viburnums is aided by birds and mammals. Various authorities attribute the dispersal of viburnum seed to birds, but no viable hobblebush seed was recovered after force-feeding it to various species of birds (Gould 1966). Small mammals were thought to be the most important dispersal agents for hobblebush seed. Specific information about the dispersal of seed for the other species was not found.

Viburnums may regenerate either from seed or vegetatively by root suckering, sprouting, or layering. Invasion of new areas is by seed followed by root suckering or layering of stems. In Connecticut, an almost pure stand of nannyberry, about 50 x 50 feet in size, resulted from the establishment of only a few seedlings followed by extensive root suckering (Niering and Egler 1955). Thus practically the entire community had a common root system. In a study in New York, hobblebush regeneration was mainly vegetative, especially by basal sprouting; and very few seedlings were found (Gould 1966). Hobblebush also readily produces layers from prostrate branches, which often remain attached to the main stem, forming loops. These loops fre-

quently trip the unwary traveler and are the source of the common names of the plant—hobblebush, tangle-legs, and witch hobble.

The viburnums vary considerably in height at maturity. Mapleleaf is the smallest, to about 6 feet, and nannyberry grows tallest, about 30 feet. Species reaching about 10 feet in height are arrowwood, hobblebush, and witherod; but hobblebush may grow as a low prostrate shrub, less than 5 feet tall. Blackhaw and cranberrybush are tall shrubs (table 1). Growth-rate information is scanty. Nannyberry in Connecticut was 15 to 18 feet tall at 26 years (Niering and Egler 1955).

Viburnums are characteristic of the shrub layer in the hemlock - white pine - northern hardwood forests, the spruce-fir forests, and the mesophytic forests of the Appalachians. They are well adapted to survival and growth under shaded conditions. Shade may be a requirement for optimum growth and development of arrowwood (Hotts 1931), hobblebush (Gould 1966), and mapleleaf viburnum. Since viburnums are also often found in forest edges, along hedgerows and right-of-ways as well as along the edges of swamps and bogs, they are capable of growth in full or nearly full sunlight. Characteristic of these sites are blackhaw, cranberrybush, nannyberry, and witherod. Viburnums are capable of forming relatively pure, closed stands either under a canopy layer or in the open, thereby excluding the regeneration of other species of plants. This has been reported for hobblebush (Gould 1966) and nannyberry (Niering and Egler 1955).

USES

Viburnums form a minor but important segment of the diet of many birds and mammals. The fruits are eaten by deer, beaver, rabbit, chipmunk, squirrel, mice, skunk, grouse, pheasant, wild turkey, and numerous species of song birds including the cardinal, cedar waxwing, and robin. The twigs, bark, and leaves are eaten by deer, moose, and beaver (Martin et al 1951).

Hobblebush is one of the major winter foods of the white-tailed deer in New York (Gould 1966, Townsend and Smith 1933, Webb 1959) and disappears rapidly when deer populations exceed the carrying capacity of the range. In Massachusetts, witherod is an important winter food of white-tailed deer, although other species of viburnum are also taken in lesser quantities (Hosley and Ziebarth 1935). Summer feeding by deer on hobblebush (Gould 1966) and arrowwood (Cook 1946) has been reported. The bark and tender stems of maple-leaf viburnum and arrowwood were preferred winter foods of the cottontail rabbit in central Massachusetts (Sweetman 1944).

In feeding tests of hobblebush seeds and fruits, the pulp was probably distasteful to small mammals, because they invariably consumed the cleaned seed first. Furthermore, samaras (fruit) of sugar maple were preferred over either cleaned seed or dried fruit of hobblebush (Gould 1966).

In Maine, grouse consume the fruit of arrowwood, cranberrybush, and witherod during the fall, but make little use of viburnums during the rest of the year (Brown 1946). They apparently do not eat the buds.

The nutritive content of hobblebush twigs (Silver and Colovos 1957) and seeds and pulp (Gould 1966) have been measured. The twig results indicate that, though palatability is high, protein content and protein utilization are low. Carbohydrate content and utilization are comparable to similar browse, but the ash fraction, which contains the essential minerals, was twice as high as in other browse species tested. The seeds and pulp have moderate protein levels and high carbohydrate levels, but low ash content. The differences between the nutritive values of the twigs and seeds are striking. Nutritive content values for arrow-

wood, nannyberry, and witherod show differences between the twigs and fruit similar to those of hobblebush, as well as differences between species (Bump et al 1947). But it is hard to evaluate these data because the plants were grown on different soils, under different climatic conditions, and probably under different stand conditions. All of these factors could affect the nutrient content of the plants and the distribution of nutrients within the plant.

Viburnums are an important component of forest-edge and hedgerow cover types that provide shelter and food for small mammals and song birds (Bump et al 1947). One authority made specific reference to the use of the hobblebush shrub layer by deer for concealment and by warblers for nesting (Gould 1966). Beaver use the larger stems of hobblebush in building their dams and houses (Baily 1927).

Blackhawk, cranberrybush, hobblebush, and nannyberry are potentially useful as human food. In 1915 a cranberrybush plantation was established at Lee, Massachusetts, to provide stock for the selection and propagation of the most useful strains (Darrow 1924). The bark of the cranberrybush has medicinal properties, and that of hobblebush, although toxic, has been used to adulterate the more expensive cranberrybush bark (Youngken 1932, Youngken and Munch 1940).

The viburnums are widely used as ornamental plants, both for their showy flowers and for their fall foliage. Many commercial varieties of various species have been developed and are now on the market.

PROPAGATION

Seed or planting stock of all viburnums discussed here is available from commercial seedsmen and nurseries. Planting stock from commercial sources is likely to be too costly for large-scale wildlife-habitat plantings. However, seed is less expensive, and it is quite practical to either purchase seed or collect a supply locally, even if only a few hundred plants are desired. It should be possible and it is definitely desirable to find local, native stands of the desired species from which seed collections can be made. The advantages of this approach are many. First, plants grown

from local seed are likely to be better adapted to local growing conditions. Second, timing the seed collection to coincide with the proper developmental stage of the seed can save time and difficulty in the nursery. Third, the characteristics of the parent plants will be known, and selection for desired qualities will be possible.

Seeds of all species of viburnum can be stored successfully for a long time provided certain precautions are observed. Immediately after collection, the pulp should be separated from the seed by maceration and water flotation. The cleaned seeds should then be thoroughly air-dried, after which they can be placed in sealed containers and kept under refrigeration at 34 to 38°F. Seeds stored under these conditions have retained viability for 10 years (*Heit 1967e*). If only short-term storage is required, the seeds need not be cleaned. The whole fruits should be spread out and allowed to air-dry. This should be done as soon as possible after picking in order to avoid heating. The air-dried fruits can then be stored in sealed containers under refrigeration at 41°F or less. With this method, mapleleaf viburnum seed showed no loss in germinability over a 2-year period (*U.S. Forest Service 1948*).

In nature, germination is normally delayed until the second spring after seed ripening. Seeds of the viburnum species discussed here all seem to require a two-stage stratification process to break dormancy. The first stage is a warm stratification period either at a constant 68°F or alternating 50 or 68°F (night) to 86°F (day) temperature. During this period

the radicle emerges from the seed and begins growth. The second or cold stratification is carried out at 41 or 50°F and breaks the dormancy of the plumule (leaf bud), which will then begin to grow when the seed is returned to a higher temperature (*Davis 1926, Giersbach 1937*). The length of each stratification period is fairly critical and has not been worked out in detail. Suggested times are given in table 4 together with the recommended stratification media.

There are alternative methods for overcoming seed dormancy. The seed may be sown immediately after collection. Depending on nursery location, this may allow enough warm days to elapse for natural warm-stratification to take place before the onset of cold weather. The seed will then germinate the first spring. If not, then germination will take place the second spring as expected. For example, nannyberry seed and fruit sown on 7 October in Ohio gave a seedling yield of about 75 percent in the following summer (*Smith 1952*). Alternatively, seed or fruit can be stored over winter and sown the following spring. Arrowwood, blackhaw and mapleleaf viburnum seed planted on 1 May in New York gave fair to good yields in the next year. Cranberrybush, which has less dormancy-breaking requirements, gave high yields when sown as late as 1 July (*Giersbach 1937*).

The simplest and perhaps the most practical method is to let nature take its course. Sow the seed either in the fall or spring, and allow a full summer for radicle development. The next winter will provide the necessary

Table 4.—Viburnum seed treatments for breaking dormancy

Species	Medium	Stratification sequence				Data source
		First stage		Second stage		
		Temp. °F ¹	Months	Temp. °F	Months	
Mapleleaf	Peat	68-86	12-17	50	4	(<i>Giersbach 1937</i>)
Hobblebush	Peat	68-86	5	41	2 1/2	(<i>Gould 1966</i>)
Witherod	Sand	68-86	2	50	3	(<i>U. S. Forest Service 1948</i>)
Nannyberry	Peat	68-86	5	41 or 50	3-4	(<i>Barton 1958, Giersbach 1937</i>)
Cranberrybush	Peat	50-86	2	41 or 50	1 1/2-2	(<i>Barton 1958, Giersbach 1937</i>)
Blackhaw	Peat	50-86	7-9	41 or 50	1 1/2-2	(<i>Barton 1958, Giersbach 1937</i>)
Arrowwood	Peat	68-86	12-17	50	2 1/2	(<i>Giersbach 1937</i>)

¹The two temperatures given are for night and day within a daily cycle. A constant 68°F is about as effective as alternating temperatures for most species (*Barton 1958*).

cold period, and germination will take place the following spring. One advantage of this method is that the seed need not be handled after the radicle has emerged.

The seed may be broadcast sown directly on prepared seedbeds and mulched with sawdust (the practice at the Maine State Forest Nursery) or it may be sown in drills and mulched with straw (U. S. Forest Service 1948). The advantage of sawdust is that it does not have to be removed after germination begins. It may be necessary to hold sawdust in place with something like mulchnet or to replace it periodically. Straw mulch must be removed once germination begins, to reduce the risk of loss due to damping-off fungi.

The seedlings may require shade for proper development, although this will depend on the species and location. Shade was required for best growth of hobblebush seedlings in the second year (Gould 1966), but cranberrybush seedlings were successfully raised in Maine without shade. The seedlings should be ready for outplanting on properly prepared sites after one or two seasons of growth in the seedbed.

Viburnums can also be propagated from either hardwood or softwood cuttings and by layering. These are the methods used by commercial nurseries. Layering is likely to be expensive in man-hours while softwood cuttings require special equipment such as mist chambers or greenhouses. Hardwood cuttings require the least labor and equipment but will probably take an extra year as transplants in the nursery before being ready for field outplanting. More detail about vegetative propagation is available in nursery handbooks and technical journals (Devisser 1967, Doran 1957, Hottes 1931, Klapis 1967).

Viburnums prefer a moderately fertile, moist soil (Bump et al 1947) if they are planted in open fields. Hobblebush, mapleleaf viburnum, and nannyberry can tolerate fairly

acid soils (Gould 1966, Niering and Egler 1955, Spurway 1941). Information on the pH requirements of the other species is less definite, but neutral to slightly acid soils are recommended for viburnums in general (Van Dersal 1938). Survival and growth of the planting is likely to be highly correlated with the degree of site preparation. Scalping to remove sod should be considered the minimum preparation. If the planting is to be in an old field it may be possible to plow and harrow the land the preceding season. Since plantings for wildlife-habitat purposes are often arranged in long, fairly narrow designs, plowing and disking is more practical for this type of planting than if an entire field were to be planted. Grass can also be controlled by herbicides and growth retardants. Browsing by deer, rabbits, or livestock may be the chief obstacle to early development of the plantings.

MANAGEMENT

Once the plantings are established, little maintenance should be required. Though light grazing is beneficial, browsing by deer and cattle must be kept under control because the viburnums will be unable to maintain themselves in competition with other species if overbrowsed (Bump et al 1947, Gould 1966). Undesirable competing species can be eliminated or controlled by the selective use of herbicides employed as basal sprays. If browse production for deer is a management objective, it may be necessary to periodically cut back some of the taller species to keep them within reach.

Viburnums can be controlled with herbicides. Due to the growth habit of spreading by root suckers, a significant amount of flashback killing is possible. For this reason herbicides that are translocated throughout the plant should not be used unless the entire stand is to be killed.

WILLOWS

BEBB WILLOW, *Salix bebbiana* Sarg. Also called Beak, Beaked, and Long-Beaked Willow.

PUSSY WILLOW, *Salix discolor* Muhl. Also called Glaucous Willow and Silvery Pussy Willow.

By James W. Rawson

*West Virginia Department of Natural Resources
Elkins*

RANGE

Pussy willow is found throughout the Northeast, and Bebb willow occurs in all northeastern provinces and states except New Jersey, West Virginia, and Kentucky (Fernald 1950, Gleason 1963b, Rehder 1940, Strausbaugh and Core 1953:II, U. S. Forest Service 1948). Many willow species that attain shrub size are found within the Northeast. Much of what follows may be applicable to species other than those mentioned above. In choosing a willow for shrub plantings, a species that exhibits the characteristics desired and grows well under local conditions similar to those of the planting site should be utilized.

HABITAT

Both willow species discussed here will withstand most climatic extremes encountered in the Northeast. Best willow growth is attained in rich, deep, moist, alluvial bottomlands. Moderate growth usually occurs in any sufficiently moist soil type. Willows will tolerate moderately alkaline soils, but do poorly in extremely acid or alkaline conditions (Lamb

1915). The general pH range for willows is 5.5 to 7.5 (Altman and Dittmer 1962, Spector 1956). Bebb willow is usually found in moist, sandy or gravelly, rich soils; pussy willow commonly occurs in moist meadows and along lakes and streams (U. S. Forest Service 1948). Both species possess one to a few stems and average 6 to 16 feet in height (Gleason 1963b).

LIFE HISTORY

Male and female flowers are catkins, an inch or more in length and born on separate trees. They appear before or with the leaves (Altman and Dittmer 1962, Berry 1917, Lamb 1915, Spector 1956, U. S. Forest Service 1948). Apparently bees are the chief pollinating agent. The fruit is a capsule containing many minute hairy seeds, which usually ripen in early summer but in some species during fall. The seeds are disseminated chiefly by wind and water. Pussy willow flowers in March and April, Bebb willow in May and June. The fruit of both species ripens soon after flowering (Berry 1917, U. S. Forest Service 1948). The optimum seed-bearing ages of

Bebb and pussy willow are 10 to 30 years and 8 to 25 years respectively (*U.S. Forest Service 1948*).

The seeds are small and light and number approximately 2 to 3 million per pound. The cottony mass attached to each seed facilitates wind dispersal shortly after the fruit ripens (*Berry 1917, Lamb 1915, Massey and Ball 1944, U. S. Forest Service 1948*). Seed dispersal of Bebb and pussy willow occurs in May and June and April and May, respectively (*U. S. Forest Service 1948*).

Willows also reproduce well by suckers, sprouts, and root shoots (*Bailey 1950, Edminster and May 1951, Lamb 1915, Van Dersal 1938*).

Some willows are considered pioneer species. They are all very intolerant and do not compete well where shading occurs. Willows grow rapidly in good soils and full sunlight; under such conditions, they often dominate other species (*Lamb 1915, Spector 1956, Van Dersal 1938*). Willows are generally short-lived (*Spector 1956*).

USE BY WILDLIFE

Willows are a major browse of moose throughout most of their range and a prime source of food for deer. Willow shoots and buds are eaten by many rodents (including muskrat and beaver) as well as rabbits and hares (*Martin et al 1951, Massey and Ball 1944; Shomon 1957; Van Dersal 1938*). Willow buds and twigs are utilized to varying degrees by several members of the grouse family (*Allison 1966, Martin et al 1951, Van Dersal 1938*). Certain ducks and water birds feed on willow catkins and leaves. Willow sap is reported to be utilized extensively by sapsuckers (*Massey and Ball 1944*).

Because of their abundance and thicket-forming habits, willows provide cover and protection for many wild birds and mammals (*Shomon 1957*). Streamside willows provide valuable brood cover for several species of wild ducks.

Bees utilize willow nectar to produce high-grade honey (*Lamb 1915, Massey and Ball 1944, Shomon 1957, Strausbaugh and Core 1953:II*).

PROPAGATION

Willow seeds are viable for only a few days; therefore commercial sources are not available. However, cuttings may be obtained readily from standing or newly felled willows (*Bailey 1950, Edminster and May 1951, Lamb 1915, Laurie and Chadwick 1931, U. S. Forest Service 1948*).

Willow seeds should be collected immediately after the fruit ripens. This may be ascertained when the capsule changes from green to yellowish-green. Close surveillance of the fruits is necessary. The seeds may be collected directly or—if they are in the vicinity of water—from drifts at the water's edge. The seed should be sown immediately after collection, but may be stored for as long as 4 to 6 weeks. For short storage periods (up to 10 days), the seed may be placed in closed containers at room temperature where relative humidity of the air surrounding the containers remains above 50 percent (*U. S. Forest Service 1948*).

After broadcast of seeds, the well-prepared seedbed should be cultipacked. Germination usually occurs in 12 to 24 hours. High moisture levels must be maintained in the seedbeds at least until the seedlings are well established. This may be accomplished with shading and burlap coverings. Seedlings should be transplanted at 3 to 4 weeks of age to give them more room to grow. In most cases, 1-year old seedlings are large enough for field planting (*U. S. Forest Service 1948*).

Nursery stock should be sprayed to control leaf rusts (*Melampsora spp.*) if they are known to be present. Fungus scab and black canker may harm or kill leaves and shoots of susceptible willow species (*U. S. Forest Service 1948*).

Most authorities agree that cuttings should be procured from young vigorous stems, but one source maintains that cuttings should be taken from those shrubs exhibiting normal growth because they contain greater quantities of stored materials (*Laurie and Chadwick 1931*). Two-year old sprouts are frequently used (*Lamb 1915*). Cuttings 8 to 10 inches long should be planted 6 to 8 inches deep with about two buds remaining above the level of the soil (*Edminster and May 1915*). In gen-

eral, the smaller the cutting (if protected from mechanical injury), the less chance of disease (Lamb 1915). Cuttings should be made with a sharp knife or pruning shears before initiation of spring growth. Cuttings in February are recommended for the Northeast (Edminster and May 1951, Lamb 1915). Both species of willow cuttings are easily rooted. Treatments with growth regulators are considered unnecessary, but rooting of pussy willow has been hastened by using indolebutyric acid (IBA) (Doran 1957). If cuttings are to be stored, they should be buried upright in moist sand and kept in a cool dark place (Lamb 1915). In general, planting should be done in early spring. In some cases (where the cuttings were not exposed to direct sunlight) satisfactory growth has been observed on areas planted as late as July (Edminster and May 1951, Lamb 1915).

When planting, a dibble should be used to avoid stripping the bark. Care should be exercised when closing the dibble hole to eliminate air spaces (Edminster and May 1951).

MANAGEMENT

Willows may be planted in wet areas where wildlife food or cover is desired or to protect soil from erosion by running water (Edminster and May 1951, Lamb 1915, Shomon 1957).

When willow plantings are to be established for erosion control, the following should be considered:

1. Perpendicular banks must be altered to produce a sloping bank before planting can be effective.
2. Planting should begin at the water and proceed away from it.
3. Mechanical aids are often necessary to create conditions conducive to effective planting.
4. Generally, any part of a live willow will grow if placed in moist soil (Lamb 1915).

If rapid establishment of willow is desired

for either dense cover or erosion retardation where conditions are not severe, willow stakes 2 or more inches in diameter may be driven into the bank at close intervals, during periods of low water. The spaces between the stakes may then be filled with willow brush of all sizes. Partially bury as much brush as possible. Forked stakes may be driven into the brush to hold it more securely (Lamb 1915).

In cases of severe erosion, willow poles 18 to 20 feet in length should be cut and laid on the bank at 2- to 3-foot intervals with their butts facing the stream. Woven-wire fencing is then fastened to the poles, leaving 2 or 3 feet of the poles projecting below the bottom of the wire if the bank is soft mud, and less if the bank is composed of firmer material. Wire sections about 100 feet long can be handled most effectively. After the wire has been secured to the poles, the poles are pushed over the bank together to allow the butts of the poles to sink into the mud at the water's edge. Eroding soil will lodge in the wire and facilitate natural burying of the poles. The ends of the wire should be secured by cables running up the bank and held by a deadman (Lamb 1915).

Purple-osier willow (*Salix purpurea*) is recommended for streambank plantings in the Northeast because of its resilience, ability to layer new plants, and tendency to recover quickly from mechanical damage (Edminster and May 1951). Species found to be ill suited for such plantings were coyote willow (*S. exigua*), streakwood willow (*S. holosericea*), Hooker willow (*S. hookeriana*), and *S. myrsinifolia* (Edminster and May 1951).

Frequent replacement of plantings may be necessary on streambanks where washouts occur (Edminster and May 1951). Where cuttings or nursery stock are used, an early cleaning of other vegetation may be necessary (Lamb 1915).

Troublesome willows may be controlled with foliage or basal sprays of 2,4-D or a combination of 2,4-D and 2,4-DP (Amchem Products 1969, Spector 1956, U. S. Department of Agriculture 1961b).

COMMON WINTERBERRY

Ilex verticillata (L.) A. Gray

Also called Black Alder, Canada Holly, Coonberry, Deciduous Holly, Michigan Holly, Swamp Holly, Virginia Winterberry, and Winterberry.

By Arthur W. Holweg

New York Department of Environmental Conservation
Albany

RANGE

Common winterberry occurs throughout the Northeast and beyond; from Newfoundland to Ontario and northern Minnesota, and south to southeastern Missouri, Tennessee, southeastern Louisiana, Georgia, and northern Florida.

HABITAT

Winterberry is most commonly found on wet soils, but grows on upland soils that are moderately cool and moist. On drier soils, height growth is reduced (Zucker 1966). Like other hollies, winterberry prefers soils that are fairly high in organic content and slightly acid (USDA 1967). A pH of 5.5 is about average under natural conditions (Curtis 1959).

Growth rate, form, and fruit production are best in plants growing in the open or in light shade, and free from aggressive competition. However, winterberry has been recommended for landscape planting in moist, shady locations (Kammerer 1934).

In New York, winterberry grows at elevations up to 1,800 feet in the Adirondacks and at 1,400 feet on the Tug Hill Plateau (Hotch-

kiss 1932). But farther north it typically grows at lower elevations. In Canada and northern New England, winterberry usually occurs in swamps and bogs, along shores of ponds, and thickets (Hodgdon and Steele 1958), and is common on the Coastal Plain.

In the north, the dominant trees associated with winterberry include northern white-cedar, balsam fir, eastern hemlock, yellow birch, black ash, tamarack, red maple, silver maple, and American elm. Shrubs commonly found growing with winterberry are hobblebush, alders, blackberries and raspberries, red-osier dogwood, swamp red currant, swamp black currant, American hazelnut, red-berried elder, highbush cranberry, bunchberry, yew, and American fly honeysuckle (Curtis 1959, Hodgdon and Steele 1958). Southward, beech, basswood, sourgum, swamp white oak, black oak, and pines take the places of the more northerly species. Swamp azalea, spicebush, pussy willow, buttonbush, virgin's bower, sweet pepperbush, inkberry, American bittersweet, and highbush blueberry replace the more northern shrubs (Grimm 1952, Wyman 1966). The communities are quite stable.

LIFE HISTORY

Individual plants bear either male or female flowers, and the sex of a plant ordinarily cannot be determined when the plant lacks flowers or fruit. The flowering period varies from April to July over the entire range and is later in the colder locations. Flowers are greenish or yellowish-white and inconspicuous, but attractive to bees. Male blossoms are borne in clusters, each cluster attached to the twig by a common stalk. The female blossoms occur singly. Flowers are borne on the basal part of the current-year's twig growth (Neal and Pease 1954). Because of relatively late blooming, frost damage to flowers is infrequent, but may occur in frost-pocket locations.

The fruits are berry-like, about $\frac{1}{4}$ -inch in diameter, and bright red when ripe in September or October. However, summer drought may cause the developing fruits to atrophy. The ripe fruits show best after leaf fall, and often persist on the plants until January or later. Dissemination of the fruit is by birds and by mammals such as raccoons and squirrels.

The fruits of some holly species have been reported as poisonous to man (Hottes 1949), but it is doubtful that any of the North American species is toxic (Kingsbury 1969).

Vigorous plants that have attained good size may bear several thousand fruits. Age of plants at first fruiting has been reported as 3 years where plants were growing in full sunlight (Spinner and Ostrom 1945), and 5 years on less favorable sites. Average height at maturity is about 9 feet, but plants may range from 3 to 20 feet, and rarely to 25 feet.

Winterberry reproduces by means of seed, suckers, and layers. Seeding is the most common method of spread, due to the attractiveness of the fruits to birds and mammals. Undigested nutlets are passed through animals and deposited in their droppings.

Winterberry does not compete well with aggressive faster growing associates. However, once established, its ability to send up numerous root suckers enables winterberry to maintain itself in a suitable situation. Survival is also favored by the fact that winterberry stems are not preferred foods of deer, cottontail rabbits, or snowshoe hares. Winterberry

tolerates partial shade and often persists in the forest understory.

USE BY WILDLIFE

Winterberry provides food—fruit, browse, or both—for many species of wildlife. The principal browsers are deer, moose, cottontail and snowshoe hare. The fruit is eaten by various small mammals and more than 48 species of birds. Reported consumers include raccoon, white-footed mouse, red squirrel, ring-necked pheasant, ruffed grouse, sharptailed grouse, bobwhite, black duck, wood duck, robin, pine grosbeak, brown thrasher, waxwing, catbird, flicker, thrushes, bluebird, starling, and many other small birds (*personal communications from J. W. Alger, G. T. Chase, A. J. Fordham, N. Hotchkiss, H. L. Mendall, A. E. Patton, A. Sonborn, Sally Spofford, D. Q. Thompson, and J. E. Tanck*).

Because winterberry seldom forms extensive stands, the cover it provides is usually inferior to that provided by plants such as alders, gray dogwood, sumacs, hawthorns, or greenbriers. But where the latter plants grow in association with winterberry, it may enhance the total cover value, particularly for those small birds that nest on or within 15 to 20 feet above the ground. Winterberry often forms part of such cover in gullies, ditches, and other wet places.

Because winterberry ranks low in browse preference, it can persist in an understory unless serious overbrowsing occurs.

PROPAGATION

Planting stock and seed can be purchased (*NE Reg. Tech. Serv. Ctr. 1971*), and winterberry can be propagated from either cuttings or seed. Fruits number about 2,000 per pound (*Van Dersal 1938*) and each ordinarily contains 4 to 6 seeds. The yield is 11 to 20 pounds of cleaned seed per 100 pounds of fruit. Numbers of cleaned seed per pound ranged from 40,000 to 129,000 and averaged about 92,000 (*U. S. Forest Service 1948*).

The Arnold Arboretum recommends that seed should be gathered in mid-October at the latitude of Boston. Seed should be cleaned and can be either sown or stratified while

fresh, or dried for storage. Fall-planted seed normally does not germinate until the second spring or later (*Kains 1945*). But stratification has produced satisfactory germination, 52 to 73 percent, the first spring after ripening. Seeds were stratified in moist sand at 68°F (night) and 86°F (days) for 60 days, then at 41°F for 60 days, followed by 60 days in sand flats. Seeds stored dry over winter and planted in the spring may germinate in the following spring (*U. S. Forest Service 1948*). Seeds should be stored dry, in sealed containers, and at low refrigerator temperatures (*Heit 1967e*). Storage life of the seeds apparently is limited to about 1 year.

Seedlings or rooted cuttings can be purchased, but the sex of such plants is usually unknown. One should buy several plants to be fairly sure of having both males and females; even this is not certain because all the cuttings may have come from one plant. Balled and burlapped plants can be obtained, and these may have the sex specified. A visit to the nursery during the blooming or fruiting periods enables one to choose plants of the desired sex.

There are several methods of vegetative propagation. The plants commonly send up suckers that can be dug each year and used as sources for softwood or hardwood cuttings that have the same sex and desirable characteristics as the parent plant. If desired, clusters of winterberry plants can be dug and divided with a spade or ax. The several plants thus obtained can be replanted. If this were anticipated or stock plants of a particular selection were desired, mound layering should work well—covering the base of each plant with a mound of soil and then cutting back the top severely. Formation of new shoots will be stimulated, and the following fall or spring the plants can be lifted and divided and the segments replanted.

One wholesale nursery propagates a named selection from softwood cuttings taken early in the growing season, while the cuttings are still very soft. The cuttings are rooted under mist. But according to Doran (1957), summer cuttings and hardwood cuttings taken until late winter will be satisfactory if kept moist and given a growth hormone treatment to aid

rooting. Winterberry cuttings rooted better in peat moss than in sand, and both summer and hardwood cuttings rooted in 18 days at 80°F.

It is probably easiest to root winterberry from cuttings with foliage. Cuttings 3 to 6 inches long should be made from twigs of the current season, with foliage that has just matured. One-third of each cutting should be inserted in the rooting medium, and the propagating area should be covered with glass or plastic to insure high humidity without misting. New growth matures from late spring to midsummer, and maturity is indicated by foliage change from light green to medium or dark green.

No direct-seeding has been done on a large scale and some direct-seedings at Newcomb, New York, were not successful (*Webb and Patric 1956*). Delayed germination makes evaluation of such efforts difficult. The Soil Conservation Service, after planting trials from New York to Maryland during the late 1930s and 1940, did not endorse winterberry for conservation plantings (*Edminster and May 1951*). Included in their nine criteria were two that could serve to restrict use of the species: site adaptability and availability. Many planting sites lack the moist, acid soils with high humus content that winterberry prefers.

Some people who have moved winterberry from the wild to their own properties report excellent establishment. Plants at least 2 years old are recommended, and older plants would be preferable. Late fall, especially in dry seasons, is a good time to transplant these shrubs from the wild because the typically swampy habitat is usually driest then. Also male and female plants usually can be distinguished.

MANAGEMENT

Female winterberry plants must have a pollen source close by if they are to bear fruit. The pollen need not be from a male winterberry, but if a male of another holly species is present it must flower at the same time as the female winterberry (*Fogg 1960*). The male winterberry or other holly should be within 40 feet of the female for good pollination. Many people who grow hollies as ornamentals set plants of both sexes in the same hole to insure

pollination. The pollen from one male should be adequate to pollinate several female plants (*Link 1945*). To realize the wildlife potential of this species, it is advantageous to have a preponderance of female plants in any planting.

Winterberry in the vicinity of rural or suburban residences will have tremendous eye appeal in the fall and early winter. Excellent landscape effects are obtained by using winterberry with broadleaved evergreens and low growing conifers (*Zucker 1966*). The increasing availability of selected forms enables tailoring the plantings to the site. Incorporating peat in soils, maintaining a good mulch for the first year, and planting to take advantage of natural moisture should help the plants get a thrifty start.

Because winterberry grows upright and tends to be bare in its lower framework, it is not practical to try to get much leafing close to the ground. Better form can be achieved by pinching basal shoots, thus inducing lower branching, and plants can be encouraged to

fruit better by cutting out some of the oldest stems every few years. Such measures could be practiced where the plants are showpieces. On a less intensive basis, a hedgerow of winterberry could be cleaned of competing vegetation periodically. If such a planting were used on a wetland area, the placement could be made to insure that the routine mowing would help release the winterberry from competition with other woody growth.

Winterberry ordinarily does not require protection from insects or diseases.

Nurseries are selecting plants that have good fruiting qualities and compact form or other desirable growth habits. Breeders are trying to develop small plants with superior foliage (*Dengler 1957*). As these superior selections become better known, the fine ornamental qualities of winterberry will increase its popularity considerably. The disadvantage of having separate male and female plants will be partly overcome by the increasing popularity of hollies and through grafting or hormone spraying.

WITCH-HAZEL

Hamamelis virginiana L.

Also called Café DuDiable (Quebec), Common Witch-Hazel, Hamamelis, Long Boughs, Pistachio, Snapping Alder, Snapping Hazel, Snapping Hazel-Nut, Southern Witch-Hazel, Spotted Alder, Striped Alder, Tobacco Wood, White Hazel, Winterbloom, Witch-Hazel, and Wood Tobacco.

By Gene W. Wood

Pennsylvania State University
University Park

RANGE

Witch-hazel is a wide-ranging species found across southeastern Canada and most of the eastern United States except southern Florida and the Gulf Coast. The species discussed here includes the one formerly called *H. macrophylla* Pursh., but is distinct from vernal witch-hazel (*H. vernalis* Sarg.), which occurs in the Ozark region (Little 1953).

HABITAT

This species is found over a wide variety of climatic conditions. It ranges from areas with winter temperature lows of -40°F to southern areas where summer temperatures commonly exceed 100°F . Low temperatures probably have little effect on growth of this shrub because winter-kill is rarely noted; and I found no mention of sun-scald.

Precipitation requirements are between 35 and 50 inches of annual rainfall. The plant is hardy and suffers little even in drought years. Growing-season lengths vary from 2 to 10 months over the range of the species.

Witch-hazel is found on a wide variety of

sites. It may be found on high, dry mountain ridges as well as along small valley streams and lake edges. Soils may range from stony or loamy sands to silt loams. It is not usually found on organic soils, but is found on soils of both low and relatively high organic matter content. Individuals are particularly conspicuous on talus slopes, where few other plants are able to sustain themselves. It readily acclimates to droughty soils with low nutrient availability, but is also capable of growing well on better sites when given the opportunity. Witch-hazel is rather insensitive to soil reaction, but grows best at about pH 6.0 to 7.0 (Hosley 1938). Witch-hazel also withstands shaded, air-polluted, city conditions (Kammerer 1934).

As the broad geographic range and wide variety of sites indicate, this shrub is found with numerous associates. On the talus slope sites it is commonly found with sweet birch, paper birch, and chestnut oak. On sandy lowlands and upland plateaus it may be found beneath a canopy of white oak, black oak, scarlet oak, and red maple. On the more poorly drained areas witch-hazel may be found with sycamore

and American elm, and occasionally alongside black walnut on moderately drained soils. In the bottomlands, the shrub will be found with swamp white oak and shagbark hickory.

Witch-hazel is not a pioneer species, although it may sprout vigorously from stumps on cutover areas. Seedlings will also appear on these newly opened sites. The shrub is almost always found as part of the understory and may often make up a significant part of this layer, especially on droughty sites. The majority of stems are from sprout origin and may form relatively distinct communities in the understory due to their growth habit of dense clumps with interlacing tops.

When the tree canopy is removed and the witch-hazel is left undisturbed, it will dominate the site for a short time only. Stump sprouts and seedlings of tree species will reclaim dominance through their more vigorous height growth.

LIFE HISTORY

Witch-hazel is peculiar in that it flowers in the fall, from September to November. The flowers are bright yellow and quite conspicuous after leaf-fall. They may often be seen covered with snow.

The fruit that began development the previous year is usually ripe while the flowers of the current year are blooming. The ellipsoidal-shaped fruits are two-beaked at the apex and are borne in pairs at the point of the original flower cluster. They are pale green, turning to brownish yellow on ripening. These woody capsules contain two dark chestnut-brown to black shiny seeds; each about $\frac{1}{8}$ x $\frac{3}{8}$ inch (*Hosely 1938*). Ripened capsules are usually available from 6 August to December (*Van Dersal 1938*).

When the capsule is completely ripe, the seeds are ejected—with a distinct snapping sound. They may travel several feet. Seed production is variable, abundant in some years and almost nonexistent in others. Production seems to be higher in wet years than in dry years.

Seed production will be greater on stems that are growing either in the open or along forest borders. Plants under tree canopies—though they flower lavishly and appear to be

as healthy as those in more open areas—rarely produce comparable amounts of seed. Production varies from one individual to another on the same site.

Seed may be collected just before full ripening of the capsule. Ejection of the seed will occur while the fruits are in warm dry storage.

Witch-hazel may be regenerated from seed or stump sprouts, or by suckering to a limited extent. Seedling reproduction is not common under closed canopies, but does occur on recently opened sites. The major source of reproduction is from clumps of sprouts that originate from one single stem. After 8 to 10 years, the parent stem is not particularly obvious. Sprouting may occur from cut stumps or stumps of shrubs killed by fire.

Among young, well-spaced plants growing on fertile nursery soils in Massachusetts, the growth period was 18 weeks, 24 April to 28 August. Maximum growth occurred in June, and 90 percent of total growth occurred from 15 May to 7 August (*Kozlowski and Ward 1957*).

Growth rates of seedlings may range from a few inches per year on dry sites to several feet on moist areas. Height growth is greatest in the first few years, then slows down, the stem increasing in diameter and branching out. The leader becomes inconspicuous at this point and the crown becomes rounded and begins to bend over toward the ground, giving the appearance that the crown is too heavy to be supported by the trunk. At this stage seed production will be at its peak and shoot growth at its minimum. New shoots on the branches will rarely be more than 1 inch long.

Stump sprouts grow more vigorously than the other two forms of reproduction. Sprouts I have observed grew as much as 4 feet in a single season, even on dry sites. The sprouts show a great deal of variation in ability to make this type of growth. Stems of the same age from the same clone may vary from 6 inches to 4 feet in height. Total height is rather hard to measure, because the larger individuals have no distinct leader. The tops of the crowns are commonly 10 to 15 feet from the ground, but a total height of 25 feet and a spread of 15 to 20 feet may be reached by this species (*Bailey 1935, Sargent 1949, Spector 1956*).

Witch-hazel has been considered relatively free from insect and disease attacks (*Hosley 1938, Van Dersal 1938*), but is commonly plagued by aphids, which cause two types of galls. The cone-gall, which appears on the leaves in mid-summer, is the more common. These galls may form dense clusters, and the aphids from them may completely defoliate the shrubs. The gall is conical in shape and scarlet red in color. A less common gall is the spiny witch-hazel gall, which occurs on the flower bud and prevents fruiting. For both of these gall-diseases, birches are alternate hosts (*Comstock 1950*). Presumably, witch-hazel growing beyond the range of birches will not be infected.

USE BY WILDLIFE

The leaves and shoots of witch-hazel are browsed by deer in varying degrees, depending upon the range condition. In areas where there is a wide choice of foods in large quantities, witch-hazel may rarely be eaten, though in unproductive areas it may be a staple in the winter diet. Witch-hazel was considered generally of low value to wildlife although it composed 5 to 10 percent of the diet of white-tailed deer in New York (*Martin et al 1951*). In the mixed-oak forests of central Pennsylvania, the shrub has a great deal of value since it is able to reproduce and maintain itself where other species cannot.

Chemical analysis of the shoots and leaves indicate that the concentrations of crude protein, calcium, and phosphorus in the leaves are about 10 percent, 0.81 percent, and 0.11 percent, respectively. Shoots contain about 6 percent crude protein, 0.56 percent calcium and 10.4 percent phosphorus (*Wood and Lindzey 1967*).

The bark of witch-hazel is occasionally used by beaver, squirrels, and rabbits. Browsing and bark-stripping by cottontails severely injured witch-hazel stands in Massachusetts (*Sweetman 1944*). Seeds are utilized by turkey, bobwhite, pheasant, and squirrels (*Hosley 1938; Martin et al 1951*). Buds and flowers as well as seeds are eaten by ruffed grouse (*Hosley 1938*).

Thickets of witch-hazel provide cover for wild animals. The thickets form windbreaks

and escape cover for small birds and mammals.

PROPAGATION

Witch-hazel can be propagated from cuttings or seed. Seed is available commercially after good seed years and 1970 prices for cleaned seed were about \$9 to \$10 per pound; a pound contains 8,700 to 10,900 seeds (*Swingle 1939, U. S. Forest Service 1948*). Cleaned seed is ordinarily pretreated and sown in spring, but fresh seeds can be sown in late summer.

Ripe untreated seeds ordinarily take 2 years to germinate (*Van Dersal 1938*). They exhibit double dormancy, which can be broken in two ways. If late summer planting is desired, the seeds should be collected before they ripen completely and sown by early September (*Heit 1967e*). In Iowa, seeds that were immature yet past the milk stage were collected in late August and planted immediately. They germinated 90 percent the following spring (*Titus 1940*).

If immediate planting is not desired, the seeds should be collected later, when the fruits are dull orange-brown or blackened and just before the capsules split to eject the seeds. The fruits should be spread out to dry, and the capsules can be removed by screening. Cleaned dried seeds can be stored in sealed containers at 41°F for 1 year without loss of viability (*U. S. Forest Service 1948*).

To prepare for spring sowing, seeds can be stratified over winter in a sand/peat mixture at 41°F or can be hot-water soaked, then warm-stratified for 60 days at 68 to 86°F and then cold-stratified for 90 days or longer at 41°F (*Chadwick 1935, Swingle 1939, U. S. Forest Service 1948*). The latter treatment may be better, but more research on dormancy-breaking treatments is needed. In a test of pretreated seed, germinative capacity was only 17 percent, but potential germination was 81 percent (*U. S. Forest Service 1948*). Another test yielded only 324 usable plants per pound of seed (*Swingle 1939*).

In the nursery, late-summer sowing should be done shortly after the seeds are gathered. The beds should be mulched with burlap, straw, or leaves and the mulch removed at ger-

mination time in the spring. Spring sowing of stratified seed is done as early as soil conditions permit. Seed may be broadcast or planted in drills (preferred), with 8- to 12-inch spacing. Surface soil should be kept moist until germination is complete. If untreated seed is used, the beds should be mulched and kept intact until the following spring (*U. S. Forest Service 1948*).

Witch-hazel should be planted on rather moist peaty or sandy soils (*U. S. Forest Service 1948*). The best natural seedbeds are rich forest soils in partial shade. However, it appears that witch-hazel will germinate and grow wherever there is enough decomposed litter to hold moisture and provide a rooting medium.

Field sowing was not discussed in the literature, but it appears that the best results would be obtained from spring sowing of stratified seed. Late-summer sowing could be done, but at a high risk of depredation from birds and small mammals. In either case the sowing should be done on organic-matter accumulations, preferably in contact with humus or peat.

Propagation from cuttings has not been considered easy because of considerable mortality of rooted cuttings during the first winter (*Doran 1957*). But in one test, cuttings rooted 92 percent in sand in 76 days without treatment (*Chadwick 1944*). With species closely related to *H. virginiana*, fair to good results were obtained from cuttings treated with IBA (50 mg/l) for 20 to 22 hours. High relative humidity, 85 to 90 percent, gave twice as much rooting as 65-70 percent humidity (*Doran 1957*).

MANAGEMENT

The primary objective in managing for witch-hazel is to provide a food source on normally nonproductive areas. Witch-hazel can take advantage of these sites and provide food and cover where many other shrubs would not be able to sustain themselves. The seed will be utilized by song and game birds. The shoots and foliage will be taken by deer, rabbits, and beaver.

The shrub is often planted as an ornamental, although foreign species or horticultural varieties are used more often than the native species. The showy fall flowers and heavy summer foliage make witch-hazel desirable for roadside plantings and picnic areas.

Witch-hazel may be grown in full shade or in full sunlight and on dry as well as moist sites. The very best production will be under a thin overstory canopy on moist sites. Seed production will be high along forest borders.

Control of witch-hazel with the pelleted herbicides fenuron, dicamba, and picloram is effective (*Eichert 1965*). Stumps may be treated with herbicides to control stump sprouting. Witch-hazel is very susceptible to light fire. Top-kill is easily achieved through very light controlled burning where only the recent litter is destroyed.

MISCELLANY

The twigs, leaves, and bark are used to prepare witch-hazel extract for shaving lotions and sprain or bruise ointments. Fresh leaves are astringent because of high concentrations of tannin (*Krochmal et al 1969*).

CANADA YEW

Taxus canadensis Marsh.

Also called American Yew, Buis de Sapin, and Ground Hemlock.

By Arthur M. Martell

Acadia University
Wolfville, Nova Scotia

RANGE

This species occurs in all the provinces from Newfoundland to Manitoba, and extends southward to western Virginia, eastern Kentucky, and northeastern Iowa; the southward range in the Northeastern States is mostly in the uplands (Fernald 1950, Gleason 1963a). However, Canada yew has been practically extirpated where deer populations are or have been exceptionally high—notably in New York, Pennsylvania, Michigan, and Wisconsin (Leopold *et al* 1947).

HABITAT

Canada yew prefers a cool moist climate. It grows best in shady situations and on well-drained silt loam (Bailey 1933), and is best adapted to soils with a pH of 5.0 to 7.5 (Altman and Dittmer 1962, Spector 1956). Being highly shade-tolerant (Spector 1956), it is found mostly in shady woods and thickets, in bogs, and on cool banks (Bailey 1933, Fernald 1950, Gleason 1963a).

Canada yew is (or was, before eradication by deer) a common shrub of the hemlock-white pine - northern hardwood region, which

dominates the northern half of the Northeast, and of the mixed mesophytic forests of the Allegheny Mountains. It is also found in bog remnants in the beech-maple forest region west of the Alleghenies and is scattered in the oak-chestnut forest region to the east, but not in eastern Maryland and New Jersey (Braun 1950).

Throughout its range, Canada yew occurs primarily as a characteristic shrub in mature-successional-stage or climax forests.

LIFE HISTORY

Canada yew flowers are single-sexed, but both sexes are usually borne on the same plant (Bailey 1935), unlike most of the exotic yew species. The male flowers are solitary or in small spikes from the leaf-axils, and the female flowers are on short axillary shoots. Flowering occurs in April to May, and the fruit ripens during July to September (U. S. Forest Service 1948). The fruit at maturity is one bony-coated seed, more or less surrounded by a scarlet, fleshy, cuplike disk, about 5 mm long and open at the top (Fernald 1950, Gleason 1963a).

No information about the youngest or oldest seed-bearing age, seed production per plant, or the dissemination of seeds was found. Some seed is produced almost every year (*U. S. Forest Service 1948*), but fruit crops are usually light and irregular (*Van Dersal 1938*).

Canada yew is more cold-hardy than any of the exotic yews (*Rehder 1940*).

USES

Canada yew is browsed year-round by moose (*Peterson 1955*), and is a choice winter food of deer (*Taylor 1961*). However, yew does not withstand much browsing; for example, yews planted for wildlife purposes in New York were practically destroyed by deer (*Smith 1964*). This preference by deer and other wildlife is remarkable because the seeds and wilted foliage of Canada yew may fatally poison livestock. The needles and seeds contain toxins that act as a heart depressant (*Bump et al 1947*).

Canada yew was not harmed by rabbit browsing in a Connecticut study area where many other shrubs were severely damaged (*Sweetman 1944*).

The fruits of Canada yew are eaten by ruffed grouse (*Bump et al 1947*), pheasants, and a few species of nongame birds (*Hosley 1938*). In Massachusetts, yews (species not stated) attracted starlings, cedar waxwings, robins, bluejays, and squirrels in mid-October when the fruit ripened (*Fordham 1967*).

Canada yew is used much less in landscaping than exotic yews, particularly English and Japanese yew, because the native species is less adaptable and produces less fruit (*Hosley 1938*). However, Canada yew was rated excellent for roadside use in "cool" locations (*Wisconsin Conservation Department 1967*).

PROPAGATION

Seed or planting stock probably is not available commercially (*Northeast Reg. Tech. Serv. Cent. 1971*). Seeds may be collected in the fall, but only fully mature, plump, scarlet fruits should be harvested. They produce the most successful seedlings. The seeds can be extracted by mixing the fruits with sand and screening out the seeds or by macerating the

fruit in water. If the fruit-water mixture is allowed to ferment a few days, the seeds are more easily separated (*Heit 1969*). Yields in four samples averaged about 21,000 cleaned seed per pound and ranged from 15,000 to 32,000 (*Swingle 1939, U. S. Forest Service 1948*). Cleaned seeds may be stored for a few years under sealed refrigeration at 32 to 40°F (*Heit 1967d*).

Little specific data on germination in Canada yew is available, but the following information for other yew species may apply. Yew seeds are not hard-coated and do not require scarification. They are extremely dormant and require a warm treatment followed by a cold treatment. The shortest effective treatment consisted of a 4-month warm period (60 to 65°F) followed by a 3-month cold period (34 to 40°F); however, a 7-month warm period followed by a 2-to-4-month cold period was more effective (*Heit 1969*).

Seed stored over winter and sown in the spring produce good seedling stands early in the following spring. Beds must be mulched heavily with pine needles, wood shavings, or straw to maintain moisture during the summer. Shading may also help prevent excessive temperatures. Sowings should be made no later than July for successful stands the following spring. Fall sowings do not germinate until the spring of the second year and may produce only a partial stand of seedlings (*Heit 1969*).

Canada yew may also be propagated from hardwood cuttings (*Bailey 1933*). Those with either 1-, 2-, or 3-year-old wood at the base rooted about equally well, but cuttings that included 3-year-old wood produced large plants more quickly. Treatment with IBA (50 mg/l for 18 hours) may increase the rooting. Sand, sand-peat mixtures, and sandy soil have been used as rooting media; and bottom heat, about 70°F, has improved rooting in some yew species (*Doran 1957*).

In the field, Canada yew grows best in at least partial shade. It does well in open exposures provided the roots are thoroughly mulched and kept cool. However, the leaves are smaller and lighter green than when grown in shady areas. Also, a southern exposure and late winter sun or a cold north wind will

brown the foliage of exposed plants (*Bailey* 1933).

MANAGEMENT

Locally, Canada yew may have doubtful value in wildlife habitat management because of its susceptibility to damage from deer or moose browsing and its toxicity to livestock.

Perhaps the best reasons for considering yew would be those in which a wildlife purpose is coupled with landscape enhancement (*Wisconsin Conservation Department* 1967) or a desire to reestablish native species of shrubs. Need for control of yew is unlikely, and no recommendations for herbicidal treatment were found.

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GLOSSARY

This glossary has been prepared to aid readers who may not know some of the technical terms used.

Axil. The upper angle formed where a leaf or branch joins the stem.

Bract. A modified, reduced leaf from the axil of which a flower or flower stem arises.

Broadcast. To sow seed in all directions by scattering.

Calcareous soil. Soil containing sufficient calcium carbonate (often with magnesium carbonate) to effervesce visibly when tested with cold hydrochloric acid.

Callus. In plants, protective covering that forms over a wounded surface.

Cane. A slender woody stem usually arising directly from the ground, usually short-lived.

Canker. A diseased lesion of the bark and underlying tissue.

Capsule. A dry, splitting, usually many-seeded fruit of more than one carpel.

Catkin. A scaly-bracted spike of usually unisexual flowers.

Clone. A group of plants propagated only by vegetative or asexual means, all members of which have been derived from a single individual.

Cotyledon. The seed leaf or primary leaf (or leaves) in the embryo, containing stored food for the developing seedling.

Cutting. A severed vegetative or asexual part of a plant used in propagation.

Deciduous. Falling at maturity, not persistent.

Defoliate. To remove the leaves from a plant.

Division. Cutting or breaking apart the crown or other parts of a plant so as to obtain more plants.

Dormancy. Continued suspension of seed growth or development in the presence of external conditions favorable for germination.

Drift, glacial. Coarse deposits left as a result of glaciation.

Drill. 1. A small furrow in which seeds are planted. 2. A row of seeds planted by dib-

bling them into a small furrow. 3. An implement that forms a small furrow, deposits seed in dribbles, covers the seed, and packs soil over it.

Drupe. A stone fruit or fleshy non-splitting fruit with a bony inner layer, usually one-seeded.

Duff. The surface horizon of forest soils, consisting of matted dead organic matter that is only slightly decomposed, and of humus.

Endosperm. The nutritive tissue of seeds, in which the embryo is embedded.

Exotic. Introduced, alien.

Forb. Any broad-leaved herbaceous plant that is not grass-like.

Fungicide. Any chemical that inhibits or kills fungi.

Germination. The development of the seedling from the seed; sprouting.

Germination, potential. Number of seeds germinating, plus the number of sound seeds ungerminated at the close of the test, expressed in percent of the total number of seeds tested.

Germinative capacity. The percentage of seed that actually germinates, regardless of time.

Humus. 1. In soil, organic matter that has reached an advanced stage of decomposition. 2. Any organic matter in the surface layer of soil.

Inflorescence. A cluster of flowers and the manner in which individual flowers are arranged.

Involucrue. A whorl of bracts surrounding a flower cluster or a single flower or the fruits developed therefrom.

Layer. A stem or branch that takes root while still attached to the parent plant and tends eventually to become a separate individual plant.

Macerate. To separate seeds from fruit by soaking and crushing.

Mesophytic. Characterized by or pertaining to conditions of medium moisture supply.
Syn.: Mesic.

Naturalized. Originally from a foreign area but now thoroughly established locally.

Nematode. Any round, thread-like, unsegmented worm of the phylum Nematoda.

Node. The place on a stem that normally bears a leaf or whorl of leaves.

N-P-K. Nitrogen-phosphorus-potassium.

Ovule. The body that becomes the seed after being fertilized.

Perfect (flower). One having both a functional seed-bearing organ (pistil) and pollen-bearing organs (stamens).

Pericarp. The wall of the ripened ovary, or fruit.

Petiole. A thin stem supporting the blade of a leaf.

pH. A scale of numbers indicating acidity or alkalinity. Some representative values are: below 4.5, extremely acid; 4.5 to 5.0, very strongly acid; 5.6 to 6.0, moderately acid; 6.6 to 7.3, neutral; 7.9 to 8.4, moderately alkaline.

Phytotoxic. Poisonous to plants.

Radicle. The portion of the embryo from which the root develops.

Receptacle. The swollen part of a plant stem that forms the base of a flower or an inflorescence.

Release. To free plants from competition by cutting, otherwise removing, or killing nearby vegetation.

Rhizome. Any prostrate or underground stem, usually rooting at the nodes and becoming upcurved at the apex.

Rootstock. In grafting, the underground stock on which parts of desirable plants are grafted.

Rotation. The period of years required to establish and grow trees to a specified condition of maturity.

Runner. A lateral above-ground shoot that may root and form young plants at some of its nodes.

Scarification (of seed). The wearing down by abrasion of an outer more or less impervious seed coat, to facilitate water absorption and to hasten germination.

Scion. A detached living portion of a plant joined to a stock in grafting.

Soundness (of seed). Percentage of seeds that are fully developed, or sound.

Stolon. A trailing or reclining stem above ground, which strikes root where it touches the soil, there sending up new shoots, which may become separate plants.

Stratification. The operation or method of burying seeds, often in alternate layers, in a moist medium, such as sand or peat, to overcome seed dormancy.

Succession, plant. The progressive development of vegetation toward its highest ecological state; replacement of one plant community by another.

Succulent. Juicy; having a high percentage of water.

Sucker. A branch or shoot from an underground stem or root that ascends above ground and tends eventually to become a separate individual plant.

Symbiosis. The living together of dissimilar organisms with resulting mutual benefits.

Tolerance. Usually, the capacity of a plant to develop and grow in shade of and in competition with trees.

Tuber. A swollen, fleshy portion of an underground stem or root that bears small scale-like leaves with buds.

Vegetative reproduction. Reproduction from plant parts other than seed.

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AVOID PROBLEM SPOILS Through OVERBURDEN ANALYSIS

by Thomas L. Despard



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WARREN T. DOOLITTLE, DIRECTOR

The Author

THOMAS L. DESPARD is a research geologist with the Strip-Mined Area Restoration Project, Northeastern Forest Experiment Station, Berea, Kentucky.

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ABSTRACT

During strip mining of coal and subsequent grading operations, indiscriminant placement of toxic overburden strata at the spoil surface creates reclamation problems that are difficult and expensive to correct. Evaluation of overburden material before mining is begun is suggested as the most reliable means of predicting spoil quality and devising a reclamation plan. This can best be accomplished by core-drilling the proposed area and submitting the recovered core samples to a laboratory for chemical analysis. Color, pyrite content, and pH are field guides used to determine the potential toxicity of exposed overburden strata. Such guides can be used to select samples of potentially toxic strata for additional laboratory testing.

AVOID PROBLEM SPOILS Through OVERBURDEN ANALYSIS

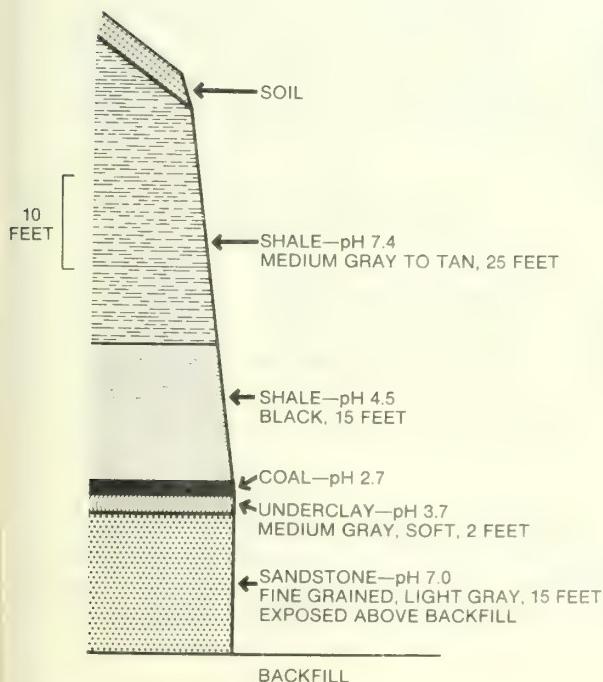
WHEN SOME COAL seams are mined, acid strata are encountered in the overburden. If this acid material is left at the surface, the spoil may be difficult or impossible to revegetate. Failure to establish vegetation and exposure of acid material at the surface lead to rapid erosion and leaching of toxic material. These processes result in increased sedimentation and chemical pollution of adjacent streams.

Because of these problems, most states concerned with strip-mining now have regulations requiring the operator to bury acid overburden material under non-acid spoil. Obviously, it is impossible to comply with such regulations if the acid strata are not recognized. After mining has been started, it is too late to identify these troublesome strata — the damage has already been done.

Figure 1 shows the highwall remaining after a mining operation on the Jellico coal seam in eastern Kentucky. The highwall is composed predominantly of medium gray to black shale, a light gray sandstone, and a thin rider coal seam. The uppermost 25 feet of shale and the sandstone at the bottom have pH of 7.4 and 7.0, respectively. The shales immediately above and below the rider seam have pH of 4.5 and 3.7. The thin rider seam is extremely acid, having a pH of 2.7.

In studying this area, we found that many spoil samples tested had a pH range of about 3.0 to 7.0. This situation could have come about by indiscriminate placement of the various highwall strata. Had the operator known the composition of the overburden before-hand, he could have selectively handled

Figure 1.—Highwall section of Jellico coal seam in eastern Kentucky.



the overburden so that the acid shale and rider coal would have been buried under the upper shale and the sandstone. If the operation had been so planned and carried out — based on information obtained before mining — it is probable that spoil more amenable to reclamation would have resulted.

It is also very likely that the extra costs of pre-mining evaluation would have been considerably less than the increased costs of attempting to rectify a problem that need not have existed. Also, in this age of increased awareness of the environment, the public relations resulting from the quality of reclamation is a factor not to be regarded lightly even though its exact monetary value is difficult to evaluate.

It is apparent then, that to formulate an adequate reclamation plan for a new mining operation, it is necessary to know beforehand what the overburden is like. One way this information can be obtained is to examine existing highwalls on the same seam in the vicinity of the new operation and to formulate a tentative evaluation of expected conditions. However, to project information from other areas is precarious. Immediately after the first cut has been made, exposing the overburden strata, the new highwall should be examined; and any modifications necessary should be made in the projected evaluation.

HIGHWALL SAMPLING

To identify strata that may produce acid spoil, it is necessary to systematically sample the overburden. When collecting highwall samples for testing, one should give strict attention to making such samples representative of the different rock types present in the highwall. If black shale, gray shale, and brown sandstone are present, representative samples should be taken from the entire thickness of the bed. Thin beds should be chipped over the entire thickness; thicker beds can be spot-sampled from top to bottom at intervals appropriate to the thickness.

Care should be taken to label the samples, and a sketch should be made of the overburden strata, showing the type of rock and its thickness and the sample location (fig. 1).

Careful attention should be given to thin clays in or adjacent to coal or rider seams because these are usually highly acid. If even small quantities of such material mix in the spoil surface, very acid conditions can result.

CORE-DRILLING

Core-drilling is the most reliable method for collecting samples to evaluate the overburden on a proposed new operation. This is the only adequate sampling method in an area where existing operations are not close by. In this way, samples can be collected and tested, and an evaluation can be made before the area is disturbed.

Evaluation of a new operation by core-drilling is especially important and perhaps should be required in areas that are considered highly sensitive to environmental damage and on coal seams known to have produced acid spoil in the past. In many instances, coal properties are evaluated by core-drilling, and overburden sampling could be done at the same time.

Another method of obtaining overburden samples is to collect the rock chips produced during drilling of blast holes. This will enable the operator to check on overburden characteristics somewhat in advance of mining. This, of course, depends on the availability of rapid analytical services. The main drawback to this method is the care required to insure adequate sampling control so that the data can be correlated with the sequence of strata being drilled.

FIELD TESTS

Field tests are not as reliable as laboratory tests, but they can give some indication of strata that may produce acid spoil. Three helpful criteria that can be used in the field are: color, pyrite content, and pH.

Color

Color can be a reliable guide to recognizing "safe" strata — if used with caution. This has been demonstrated in West Virginia where Grube et al. (1973) have accomplished

much to correlate color of rock strata and acid-producing potential. Sandstones exhibiting shades of brown, yellow, or red can be considered safe; but care must be taken to be sure that these colors extend throughout the rock and are not present merely as surface staining or fracture coatings.

These colors, characteristic of the zone of intense weathering, occur in the upper part of the highwall. Gray material is ambiguous and can be either safe or acid. Black material is always suspect, but sometimes is safe. Gray and black strata should always be checked by one or both of the following criteria.

Pyrite

Oxidation of pyrite contained in strata that have been exposed to weathering is the predominant source of acid spoil. Therefore, if pyrite is present, the material is usually acid-producing.

Pyrite can be recognized by its metallic appearance, brassy color, and hardness (it cannot be scratched with a knife). Care should be taken not to confuse pyrite with mica, which is very abundant in some strata. Mica can be recognized by its occurrence as very thin plates, its glassy rather than metallic luster, and its extreme softness. Also, mica is usually concentrated along bedding planes of the strata, while pyrite occurs as grains and streaks distributed throughout the rock. Additional information on mineral identification can be obtained from standard mineralogy texts, such as that by Hurlbut (1952).

If pyrite can be seen in overburden strata, such material should definitely be considered potentially acid-producing. However, inability to see pyrite does not mean that it is not present. In many rocks, especially black shales, pyrite may be present in a highly dispersed, very fine-grained form that is visible only under a microscope. If present in sufficient amounts, this form of pyrite is actually more harmful than the visible type, for at least two reasons: (1) pyrite that occurs as grains large enough to be recognizable by eye sometimes possesses a crystal structure that is relatively inert to oxidation; and (2) the very fine-grained pyrite is usually of a form that is susceptible to oxidation and also has

a very large surface area. Therefore, it is essential that all fine-grained strata such as shales and claystones be checked carefully for pyrite.

pH

The pH of a rock that has been exposed to weathering, even for a short time, can be used as a guide to its acid-producing potential. Rock pH can be determined by making a slurry of equal volumes of ground rock and distilled water and then by measuring the slurry with a pH meter.

Determining the pH of a rock slurry by using chemical indicators is unreliable and should not be attempted. If the pH of such a slurry is above 5.5, the rock can be considered safe. If the pH is lower, the material should be considered suspect; and samples should be submitted to a laboratory for further tests.

A pH test is useful only for weathered or partially weathered rock. The pyrite in fresh rock, such as that obtained from drill cores or freshly exposed highwalls, may not have been oxidized to form acid and can be evaluated only by laboratory tests.

LABORATORY TESTS

Field methods for evaluating rock strata are tentative. The only truly reliable method for evaluating overburden strata is to collect representative samples from either highwalls or drill cores and submit them to a laboratory for testing. Such tests should be evaluated by someone who has a background in geology and can interpret their meaning. At present, microscopic identification of pyrite in rock samples and determination of total acidity after all pyrite present in the sample has been chemically oxidized seems to be the most reliable way of testing overburden strata for acid-producing potential.

Total Acidity

Although pH can be used as a field guide, final evaluation of a sequence of strata must be based on total acidity. The pH of a material is a measure only of the acidity caused

by the concentration of hydrogen ions present.

Most of the hydrogen ions in acid spoil are derived from the sulfuric acid produced by the oxidation of pyrite and, to a lesser extent, from ion exchange reactions of clay minerals. Total acidity can be used to measure, in addition to hydrogen ions, any material present that will react with a basic material such as lime.

This additional acidity mostly involves reactions of the basic material with iron and aluminum and usually is much greater than the hydrogen-ion acidity. In other words, the amount of lime required to raise the pH of a spoil material to any given pH value depends on the amount of hydrogen ions, iron, and aluminum present; and it is this quantity that is measured by the determination of total acidity. More extensive discussions of pH and total acidity can be found in publications by Bear (1964) and Peech (1965).

Total Potential Acidity

In testing overburden strata or spoil that is only partially weathered or not weathered at all, a further complication arises in determining the acid-producing potential and lime requirements. The usual determination of total acidity measures only the acidity that has already formed in the material being tested. As this material continues to weather, any remaining pyrite may oxidize, producing additional acidity. Over a period of time, acid spoil that had been neutralized with lime could again become acid.

The additional acidity that may be produced by continued weathering can be called the total potential acidity, which can be determined by measuring the acidity after all the pyrite in the sample has been chemically oxidized. There is no way of determining the rate at which this additional acidity will form or even if it will form at all. However, by knowing that such a possibility exists, one can check spoil pH periodically to determine when

additional lime is needed. Also, situations may arise where the indicated amounts of lime required will make reclamation impractical. By proper sampling and testing, such situations can be recognized and avoided.

SUMMARY

The main objective of strip-mine reclamation is to restore the land to a condition that will prevent environmental damage. It is becoming more and more important that such areas be restored to a useful and aesthetic condition. If a strip-mined area is to be developed for a useful purpose, an effective reclamation program must be formulated and followed through to completion. A plan must be devised before mining is begun.

Thus, as much knowledge as possible must be obtained about the material to be disturbed. The best way to evaluate the overburden material adequately is to sample the area to be disturbed by core-drilling and then to test the recovered samples in the laboratory. In this way, the location of toxic strata in the overburden can be ascertained; and a mining plan can be devised that will insure burial of such material. Constant checking of the high-wall as mining progresses will also help avoid the creation of problem spoil.

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